Only a limited edition of these books has been printed. Copies are not for sale, but can be obtained by steam railway employees who are interested in electric train lighting and illumination, when request is made through the chief official of a railway department

RAILWAY ELECTRICAL ENGINEERS' HANDBOOK

ELECTRIC LIGHT AND ILLUMINATION

C. W. BENDER

SECOND EDITION
REVISED AND ENLARGED

EDITED AND PUBLISHED BY
ENGINEERING DEPARTMENT OF
National Electric Lamp Association
CLEVELAND, OHIO
1912

PREFACE

THE First Edition of the Railway Electrical Engineers' Handbook was received with such favor that the Engineering Department of the National Electric Lamp Association has found the labor of its revision a pleasure rather than a task. The original matter has been revised and enlarged, to such an extent that this may be considered practically a new book.

The many recent and important developments in electrical apparatus and in illuminating media for train lighting have necessitated this wholesale revision in producing the Second Edition. New data on the lighting of railroad shops, yards and offices have been added.

It is the intention of the Engineering Department to publish revised editions of this work from time to time, as may be made advisable by reason of changes in the art.

Readers will confer a favor by notifying us of any errors that may be discovered, as in this way it will be possible to rectify them in future editions.

C. W. BENDER.

The National Electric Lamp Association

This Association does not engage in commerce. It has for its objects the advancement of the art of incandescent lamp manufacture, and the development of the science and art of illumination. It is sustained by the following works of the National Quality Lamp Division of General Electric Co. which have adopted as their motto, "National Quality."

AMERICAN ELECTRIC LAMP WORKS..Central Falls, R. I.
BANNER ELECTRIC WORKS............Youngstown, Ohio
BRILLIANT ELECTRIC WORKS............Cleveland, Ohio
BRYAN-MARSH ELECTRIC WORKS....Central Falls, R. I.
BRYAN-MARSH ELECTRIC WORKS...........Chicago, Ill.
THE BUCKEYE ELECTRIC WORKS......Cleveland, Ohio
COLONIAL ELECTRIC WORKS...............Warren, Ohio
THE COLUMBIA INC. LAMP WORKS.......St. Louis, Mo.
ECONOMICAL ELECTRIC LAMP WORKS...New York City
ELUX MINIATURE LAMP WORKS.........New York City
FEDERAL MINIATURE LAMP WORKS........Chicago, Ill.
THE FOSTORIA INC. LAMP WORKS........Fostoria, Ohio
GENERAL INC. LAMP WORKS.............Cleveland, Ohio
MONARCH INCANDESCENT LAMP WORKS..Chicago, Ill.
MUNDER ELECTRIC WORKS..........Central Falls, R. I.
PACKARD LAMP WORKS.....................Warren, Ohio
THE PEERLESS LAMP WORKS..............Warren, Ohio
SHELBY LAMP WORKS.......................Shelby, Ohio
STANDARD ELECTRIC WORKS.............Warren, Ohio
THE STERLING ELECTRIC LAMP WORKS..Warren, Ohio
SUNBEAM INCANDESCENT LAMP WORKS...Chicago, Ill.
SUNBEAM INCANDESCENT LAMP WORKS.New York City

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SECTION I

STRAIGHT STORAGE SYSTEM

INCLUDING DESCRIPTION OF SYSTEM WITH PHOTOGRAPHS OF INSTALLATION AND WIRING DIAGRAMS OF SAME

STRAIGHT STORAGE BATTERY
Lighting System

The straight storage battery system was one of the earliest methods of securing the necessary current for the electrically lighting of steam railway passenger equipment. As now adopted, this method generally consists of suspending either 16 or 32 cells of storage batteries from the under side of the car, the cells being placed in specially constructed boxes, Fig. 3. These cells are charged at the terminals and are discharged while the car is in service, furnishing the necessary current for the operation of the electric lighting equipment.

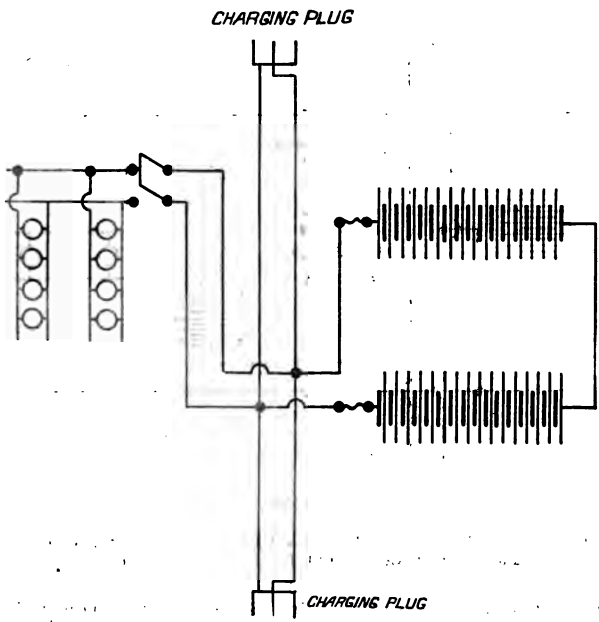


Fig. 1. Straight Storage System—Wiring Arranged for Charging and Discharging Batteries in Series

Two battery or service wires are carried in conduit along the underside of the car to the end and then run up to the distributing panel, located inside. From this point the current is distributed to the different lamp circuits through various fuses and switches.

Underneath and on each side of the car are located charging receptacles for charging the batteries. For this purpose the cars are placed at some convenient point at

the end of each run, or as often as the service runs demand, where direct current of the proper voltage is available for charging the batteries. Adjustable resistances are placed in series with the batteries upon charge for adjusting the current to the proper amount.

The current for charging is generally obtained from a standard 110-volt direct current generator. In case only alternating current is available it is necessary to convert this to direct current, either by means of a mercury arc rectifier or a motor-generator set.

In using the straight storage system the method most generally employed is to connect 32 cells of 300 ampere-

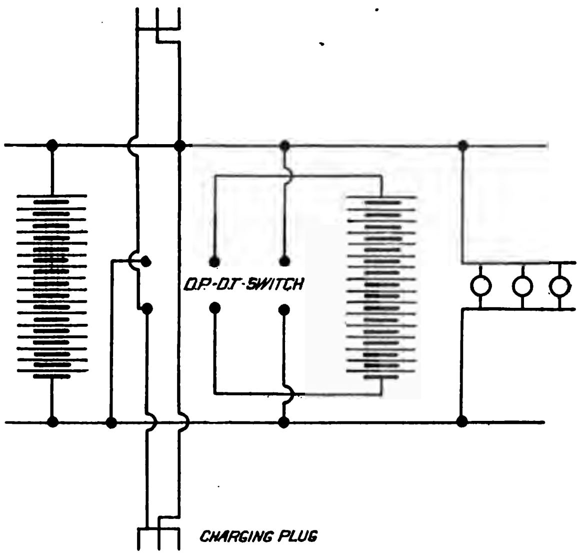


Fig. 2. Straight Storage System—Wiring Arranged for Charging Batteries in Series and Discharging in Parallel

hour batteries in series, using 63-volt Mazda lamps for lighting. This method insures the cells charging and discharging evenly. Fig. 1 shows the wiring diagram of connections with such an arrangement.

Under certain conditions it may be advisable to use a 32-volt system, and should not 300 ampere-hour batteries afford sufficient capacity, two sets of batteries of 16 cells each can be connected in multiple for discharging at 32 volts. Upon charging, they are connected in series by means of a d. p. d. t. switch and are then charged from the regular power or lighting 110-volt circuit. A wiring diagram of such an arrangement is shown in Fig. 2. This method of operation should be used only for special reasons and then only as a last resort, as the batteries, when con-

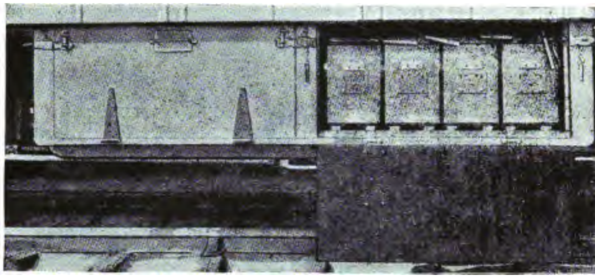


Fig. 3. Storage Battery Mounted on Car

nected in multiple, will neither charge nor discharge evenly.

Compared with the other methods of car lighting, the advantages of the straight storage system are its simplicity and reliability. There is no complicated mechanism to get out of order, and as long as the battery charge lasts, there is a positive source of current. It has one great disadvantage in that it requires that the cars be "spotted" at the terminal points for charging, thereby interfering with the yardmaster's schedule in congested yards.

The straight storage system also requires an elaborate and expensive system of yard wiring, together with a large generator capacity at terminal points. In estimating the costs of such a system, account must be taken of the interest and depreciation upon this wiring, generators, etc., together with the power losses in wiring, rheostats, and battery efficiency, all of which items probably make the straight storage system the most expensive in the long run.

SECTION II

HEAD-END SYSTEMS

INCLUDING STRAIGHT ENGINE GENERATOR SYSTEM, GENERATOR IN BAGGAGE CAR WITH BATTERIES ON ONE OR MORE CARS, BALTIMORE & OHIO, GOULD BOOSTER, AND GENERAL ELECTRIC SYSTEMS

THE STRAIGHT ENGINE GENERATOR SYSTEM

The Straight Engine Generator System as generally used consists of a 110-volt generator direct connected to a reciprocating engine or turbine, the generator set being located in the baggage car, while steam at about 90 lbs. pressure is furnished by the locomotive for operating.

To insure the lamps burning at a uniform brilliancy in the various cars, it is customary to run an equipotential or third wire system in conduit over the car roof, while connection between cars is made in the vestibule by passing the train-line wires through the roof near the end of car, thence through an opening over the vestibule to a female connector at the end of the car from which connection to the adjoining car is made with flexible wire cables.

As will be noted from Fig. 1, the system is entirely devoid of wiring complications, but has been very little used

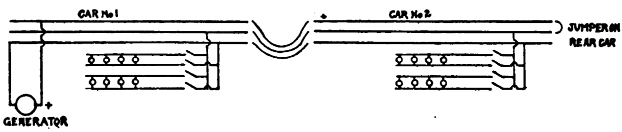


Fig. 1. Straight Electric Lighting Wiring Diagram—No Batteries

by reason that when the engine or turbine is shut off by reason of steam hose bursting, low steam, or break-down, the electric lights are extinguished and some other form of illuminant must be resorted to. A similar condition will obtain at division points when locomotives are changed. This objectionable feature has been overcome in a way by the use of a throw-over switch connecting the train circuit to a local lighting plant, but it is obvious that such an arrangement can only be a make-shift, as when a car is cut out of a train, which is common practice, some auxiliary method of lighting must be available until such time as the car is again coupled to the electrically lighted train. It can be readily seen that the Straight Engine System, while of comparatively low first cost, can be only used for through trains when run solid, from terminal to terminal, with throw-over switches at division points, and cars equipped with an expensive auxiliary lighting system of some kind, should a breakdown occur en route, while with suburban cars the same conditions hold as for through runs, except the throw-over switches are not necessary for lighting the cars at division points.

HEAD-END SYSTEM WITH GENERATOR SET IN BAGGAGE CAR WITH BATTERIES ON ONE OR MORE CARS

This is by far the most generally adopted of all head-end systems, being used by one eastern railway and a number of roads in the western part of the United States where

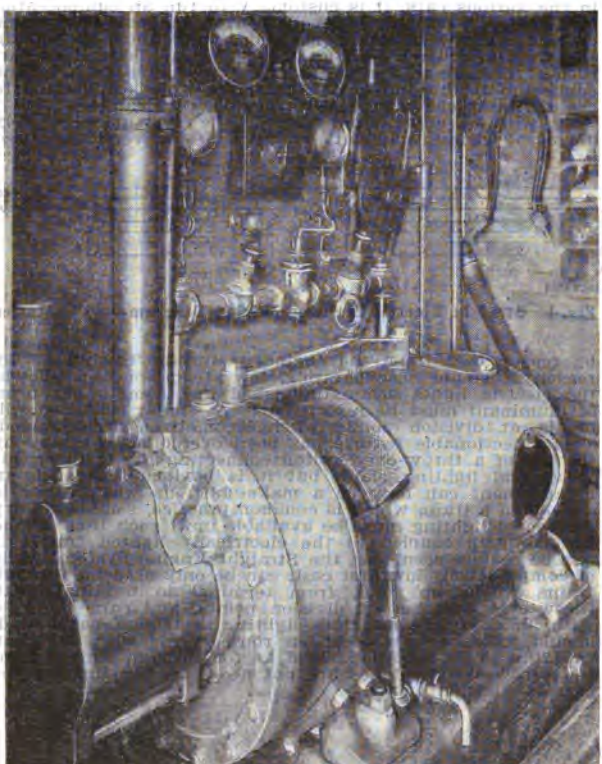


Fig. 2. 15-Kw. Curtis Steam Turbine Train Lighting Set Installed in Composite Car

the train runs are some 2,000 miles long, with practically no splitting of the train from one terminal to end of run.

This method of lighting originated in 1887 on one of the eastern roads and as installed at that time consisted of an 8-hp., three-cylinder steam engine direct connected to an 80-volt dynamo—one set of 120 ampere-hour batteries

were used but the excessive current consumption of the carbon filament lamp soon compelled the placing of batteries on each car. Later on 300 ampere-hour batteries were used, while turbine generators replaced the reciprocating engine and dynamo.

The general practice at the present time is to use three

Fig. 3. 15-Kw. Curtis Steam Turbine Train Lighting Set Installed in Composite Car

or more sets of 32-cell batteries of 300 ampere-hours capacity. When smaller capacity batteries are used each car on the train is generally equipped with a set. This allows of the train being split at any time and the cars are not required to have an expensive auxiliary system of lighting.

The generator used is generally of the Curtis-Turbine non-condensing type of 18 to 35-kw. capacity and for oper-

ating at a pressure of 90 or 100 lbs., steam pressure being supplied by the locomotive through the regular steam heat hose.

The Turbo-generator is of an interesting construction. A cross-section of the 18-kw. size is shown in Fig. 5. It is designed to operate at a speed of 4500 r. p. m. at 90 lbs. steam pressure and rated at 225 amperes at 80 volts.

The turbine wheel is fitted to the shaft with a taper fit, and held in position by a key and the back of the governor which screws on the end of the shaft. There are three sets of vanes on the wheel while the intermediates, two in number, are placed on the openings between the rows of vanes.

Bearings: The bearings are two in number, both being of spherical cast bronze and ball seated in pillow blocks, the commutator end bearing being of one solid piece and

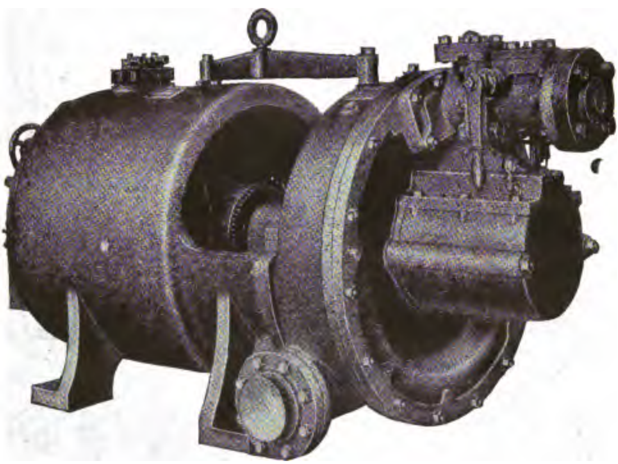


Fig. 4. 35-Kw. Train Lighting Turbine—Baggage Car Type

the main bearing split, oil chains or rings being used for conveying the oil from oil chambers to bearings.

Valve: The main valve is of the piston type operated by a fly ball governor while the emergency valve is merely a spherical or clock-wise spring which is tripped at approximately 10% over speed which forces a small brass plate to come forward closing the steam opening.

Governor: The main governor is of the fly ball throttling type and is screwed on the end of the generator or turbine shaft. It depends upon the action of a pair of interlocked weights being thrown out by centrifugal force which action is opposed by a heavy steel spring. The inner end of spring is fastened to a spindle on the end of which is screwed a small ball set in an adjustable seat or what is known as

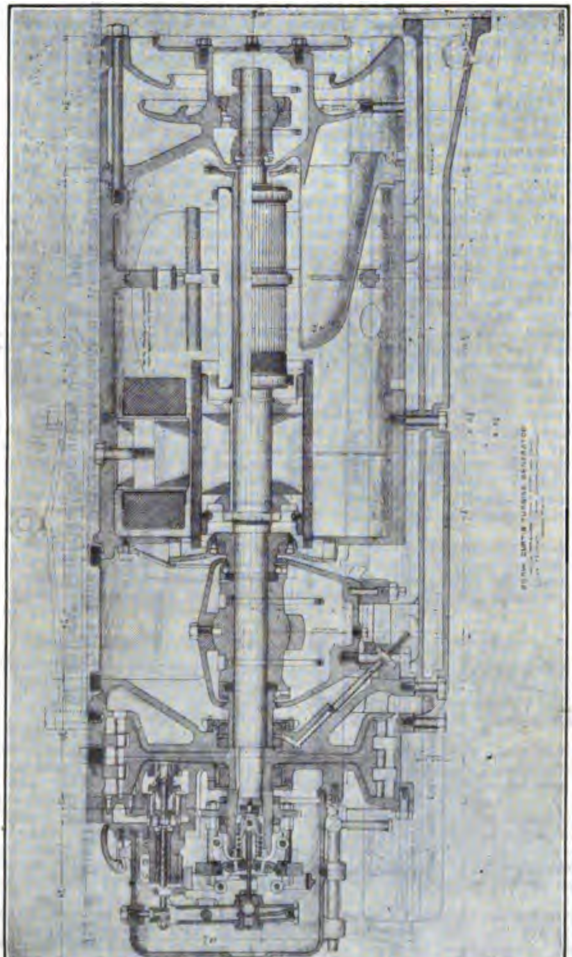


Fig. 5. 18-Kw. Curtis Turbine

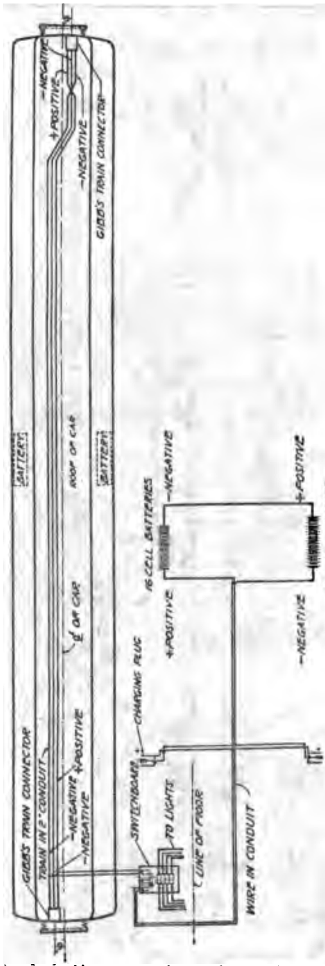


Fig. 6. Diagram of Standard Train Line and Battery Connections as Recommended by the Association of Railway Electrical Engineers, October 5, 1909

a valve lever which is fulcrumed at the center, while the other end engages the valve stem. As the governor weights are thrown out the governor spindle is drawn back, pulling the valve lever forward for proper position of load, the action of the governor depending upon the relation of the displacement pressure characteristic of the spring to that of the weights.

Car Wiring: Train line wire for this system is generally of 3/0 size; the wires on each car necessarily being transposed on each by reason of maintaining the proper voltage for battery charging. A wiring diagram as recommended by the Railway Electrical Engineers' Association is shown in Fig. 6. One of the objectionable features of this system is that the generator capacity cannot be obtained when the lamps are burning, without raising the voltage to a point where it is almost instantly destructive to the lamps. This is due to the back e. m. f. of the batteries, which rises on charge from about 2 volts at the beginning to approximately 2.5 volts per cell at end of charge. This acts automatically in reducing the flow of the current. As 63-volt lamps should burn at approximately normal voltage when the batteries are discharging or when the cells give about 2 volts, it is obvious that to increase the generator voltage, in order to fully charge the batteries, the lamps would be burned at approximately 30% over voltage. In order, satisfactorily, to operate this system it is customary when lamps are burning to adjust the generator voltage to 73 volts. This voltage is reduced at the lamps (due to drop in train line on a seven car train) to about 66 volts. During the day time, and late at night when few lamps are burning, the generator voltage is raised to 78 volts which insures the batteries at the terminals in a fairly well charged condition, without subjecting many lamps to a destructive over-voltage.

A number of railways using the head-end system have adopted a resistance for use in the lamp circuit to overcome the objectionable feature just pointed out, one of these methods of which is described in the following Baltimore & Ohio system.

BALTIMORE & OHIO HEAD-END SYSTEM

This system possesses the special feature of using automatic lamp regulators on each car to maintain constant lamp voltage. The generating equipment consists of 20-kw., 100-volt compound wound Curtis turbines, operating at a speed of 4,500 r. p. m. at 80 lbs. steam pressure.

Switchboards, with necessary instruments and overload, no-voltage, reverse current circuit breakers are provided which, with the generating equipment, are located in separate compartments at one end of the baggage cars.

Steam piping is so arranged that either end of the turbine car may be operated towards the locomotive. Batteries consisting of 32 cells of 300 ampere-hours capacity are carried on all cars of the train, except coaches and express cars, which generally average five batteries on a seven or eight car train.

Each car is provided with an automatic lamp regulator, the Gould, Safety Car Heating & Lighting Co., or U. S. Light & Heating Co. standard lamp voltage regulators, as used with their axle generator systems being used, with slight modification to adapt them to the larger voltage range met within this service. The regulators are adjusted to maintain 68 volts on the lamp circuits, 63-volt tungsten lamps being used.

The generators are operated at voltages varying from the lamp voltage to 90 volts, depending upon the amount of charging the batteries require. Normally, train line voltage is maintained between 70 and 85 volts, thus insuring that the batteries are in charged condition, or are being charged at all times. When turbines are operating during lighting hours with batteries in fully charged condition the voltage is reduced to about floating point, thus carrying the lamp load entirely on the generators and at the same time preventing overcharge of the batteries. Fig. 7 shows the wiring diagram of this system.

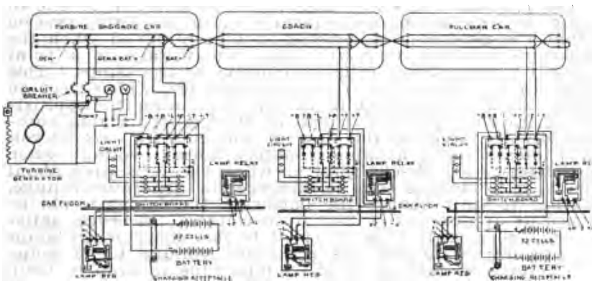


Fig. 7. Wiring Diagram—Baltimore & Ohio Head-end System

GOULD BOOSTER SYSTEM

The Gould Booster Head-end system was designed by the Gould Coupler Company to overcome the objectionable features of practically all head-end systems, viz., operating at a compromise voltage with a resultant variable candle-power and short life of lamps.

Turbine Generator: The Curtis Turbine generator of the 15-kw. type was used, the capacity of which was increased to 18-kw. by increasing the speed of the turbine from 4,000 r. p. m. to 4,500 r. p. m., while the steam nozzle was designed for 160 lbs. steam pressure in order to obtain the advantage of high pressure steam direct from locomotive.

Generator: The generator was of the inter-pole type, over-compounded to give 67 volts at one-quarter load, to 78 volts at full load. This rising voltage characteristic was necessary in order to take care of the voltage drop in the return negative main from the rear of the train.

Location of Turbine: As will be noted from the accompanying views of the equipment, the turbine generator was located on top of the locomotive between the sand and steam domes on the Atlantic type of locomotive. On the smaller types the set was located crosswise on the boiler and in front of the stack, as no other available space was to be had without changing the sand or steam domes.

The booster was located on the locomotive tender and consisted of three machines, viz., a differentially wound battery booster with a series lamp booster direct connected on the same shaft to a compound wound motor.

*The battery booster furnished the increased voltage necessary to charge the batteries, it being wound in such a manner that when the lamps were not burning the combined e. m. f. of this booster and of the generator furnished the necessary e. m. f. to bring the batteries up to a maximum state of charge; the magnetic characteristics of the booster being such that, as the conditions of charge approach a maximum value, the current entering the battery was automatically reduced. The series winding on this booster through which all of the lamp circuits passed acted to reduce

Fig. 8. Front View of Curtis Turbine Generator Mounted on Engine Class "L" Penna. Locomotive

the booster voltage upon an increase of lamp load. This tended to maintain a predetermined load on the main generator by reducing the battery charging current in about the same proportion as the lamp current increases; the action, in fact, being such that if the lamp load represented a greater value than the normal load desired to be carried by the generator,* the booster would deliver a voltage in such a direction as to cause the battery to take that portion of the load representing the overload. When the lamp load equaled the normal output of the generator, the battery booster voltage would be zero, and the batteries would be simply floating across the system. On the other hand, if no lamps were burning, the generator output would enter the battery as a charge, reducing gradually as the battery back pressure rises.

*Note.—This system not now in service.

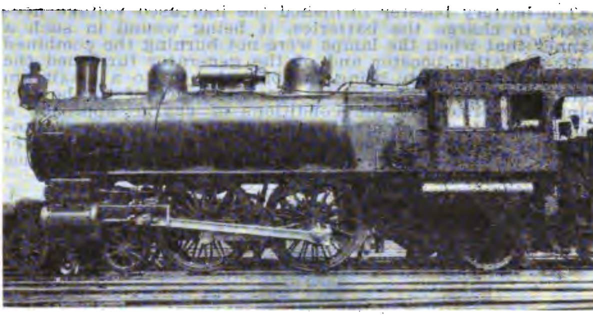


Fig. 9. Side View of Curtis Turbine Generator Mounted on Engine. Class E-3 Type, Penna. Locomotive

The lamp booster was connected in series with the lighting line to obtain a substantially regular distribution of voltage regardless of varying train lengths and load distribution.

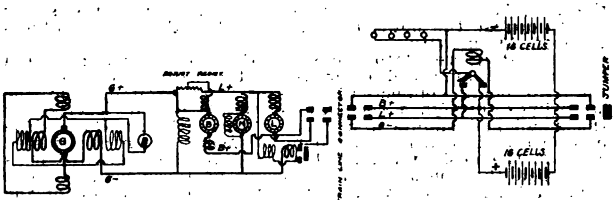
The operation of starting and stopping the generator and booster consisted of opening or closing a steam valve in the locomotive cab. Assuming that the turbine generator was not in operation, the batteries maintained the lighting on the cars on which they are located, or in case of a broken battery connection, the current would flow through the train line wires and maintain the lighting on any particular car, provided, of course, the train line couplers were connected.

Assuming that the turbine was started by opening the steam valve in the locomotive cab, the booster motor starts up concurrently with the rise in generator voltage. When the generator reached a normal voltage, such as 60, the automatic switch on the locomotive tender would close and the current would pass through the train line wires, closing transfer switches on the various cars. The turbine gen-

Fig. 10. Booster Mounted on Tender

Fig. 11. View of Couplings Between Cars

erator would then maintain the lighting load, the current passing through the lamp booster, train line wires and automatic switches to lamps and rear of train, returning through train line jumper and coils on car transfer switches to negative side of generator. The path of the battery charging current is from the generator through the battery booster and automatic switch and train line wires to the positive side of the batteries, to rear of train, and returning through the train line jumper and coils on car transfer switch to the negative side of the generator.



GOULD BOOSTER SYSTEM.

Fig. 12

Upon shutting down the turbine the reverse action takes place, the transfer switches on all cars dropping out at some minimum current value, placing each set of lamps across its own batteries. Upon a slight reversal of current the main switch opens and prevents further flow of current from the batteries into the generator or booster.

GENERAL ELECTRIC HEAD-END SYSTEM

This system consists of a Curtis Turbine generator located on the locomotive or in baggage car. The lamp voltage is maintained practically constant at the generator while a booster is connected in series with the battery, the voltage of which is adjusted to give a constant line voltage irrespective of battery voltage and load.

For automatically closing the circuit when the turbine is

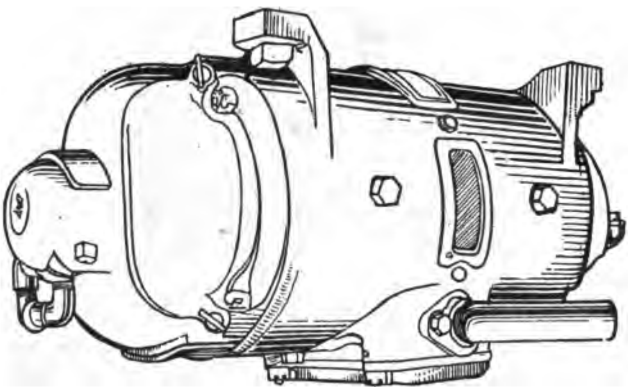


*Fig. 13. G. E. Booster

shut down, a reverse current relay is connected in one side of the line. This relay is operated by a potential coil connected across the generator terminals and closes the contacts when the normal voltage is reached. When the steam is shut off, the current from the batteries tends to reverse the flow back into the generator which causes the series coil to oppose the potential coil and allow the relay contacts to open by gravity.

The voltage regulator consists of an electromagnet, and a small coil arranged to move in the field of the former, the two being connected in series, and excited from the lamp lines through a rheostat, so that a contact carried by the small coil shunts a portion of this field rheostat. The motion of this coil is resisted by a spring which is adjusted so that the desired potential applied to the regulator coils will open the contacts. The closing of these contacts will cause a rise in voltage and vice versa, the opening of the contact causes it to fall. Therefore to maintain equilibrium, the contacts rapidly open and close, making the average

*Note.—This system not now in service.

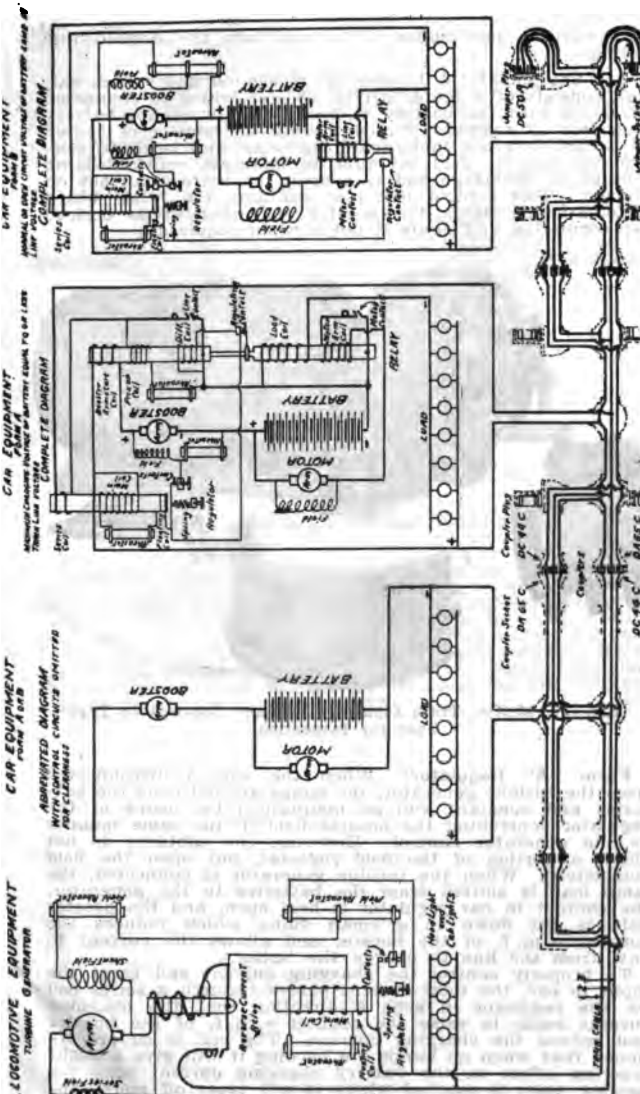


Fig. 14 GENERAL ELECTRIC SYSTEM

field current just sufficient to maintain the desired line voltage.

Car Equipment: A booster set is located under each car, and consists of a motor driven booster which is connected in series with the battery to boost the voltage for battery charging. A regulator for controlling the booster is located in a cast iron box underneath each car, and tends to control the booster field in order to maintain constant lamp voltage on discharge and to control the battery current on charge. This control box also contains the relay which automatically starts the booster set when it is desired for regulation and shuts it down when required.

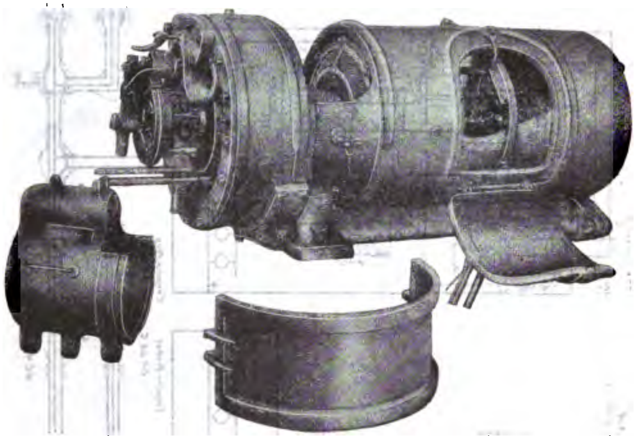


Fig. 15. 15-Kw. Train Lighting Turbine. Locomotive Type Open for Inspection

Form "A" Regulator: When the car is disconnected from the turbine generator, the lamps are fed from the batteries and constant voltage maintained by means of the regulator controlling the booster field in the same manner as the generator control. However, the contacts do not shunt a portion of the field rheostat, but open the field completely. When the turbine generator is connected, the lamp load is shifted from the batteries to the generator, the contact in car regulator is held open, and the booster field is cut down to a small value which reduces the counter e. m. f. of the booster and allows the current to flow from the line to charge the battery.

To properly control the charging current and boost the input to car, the total current passes through a series coil on the regulator in such a direction that the incoming current tends to raise the counter e. m. f. of the booster and reduce the charging current. The coil is so proportioned that when no lamps are burning it will give a slight tapering effect on the battery charging current until the gassing point is reached where it will taper off more rap-

idly until practically zero current flows at the end of charge. When lamps are burning, the maximum charging current is reduced sufficiently to keep the car input down to the predetermined maximum current. If the steam pressure is reduced or the total load is greater than the generator capacity, the line voltage will tend to drop, and allow the car regulators to come into action, giving the booster sufficient field current to cause the batteries to discharge and help out the generator.

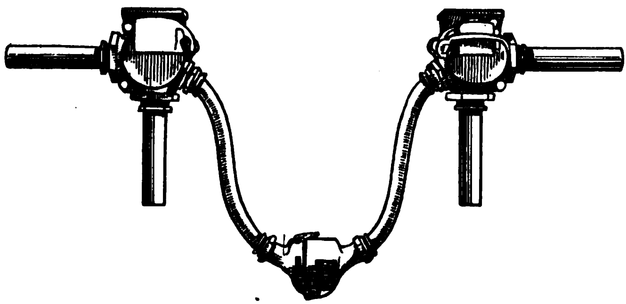


Fig. 16. G. E. Train Lighting Connectors

Form "B" Regulator: This regulator is the same as the form "A" regulator with the exception of an additional contact which closes the circuit of the second booster field, which is wound in an opposite direction to that of the first. This field comes into action when the battery voltage on discharge is higher than the desired lamp voltage. This causes the booster to "buck" instead of "boost," and on charge it also causes the booster to boost the line voltage sufficiently to charge the battery.

SECTION III

AXLE GENERATOR SYSTEMS

INCLUDING BUTTNER, BROWN & BOVERI, CONSOLIDATED, GOULD, MATHER & PLATT, LEITNER, NEWBOLD, SAFETY, STONE AND UNITED STATES SYSTEMS

ADAMS-WESTLAKE
NEWBOLD SYSTEM

Generator: The generator is of the four-pole shunt wound type with cast steel field frame. The field coils are held in place by brass retainer shoes bolted to the frame with through bolts, provided with nuts, the ends of which are peined over.

The bearings are of the ring oiling type and are covered by heads which are fastened to the frame by cap screws. These heads are provided with large oil wells and overflow pipes.

The armature coils are form wound, and the armature shaft is removable. The brushes, of which there are four sets, are carried in cast bronze brush holders which are supported by a plate attached to the generator frame.

Pole Changer: The pole changer consists of a worm or screw thread on the end of the armature shaft; the thread

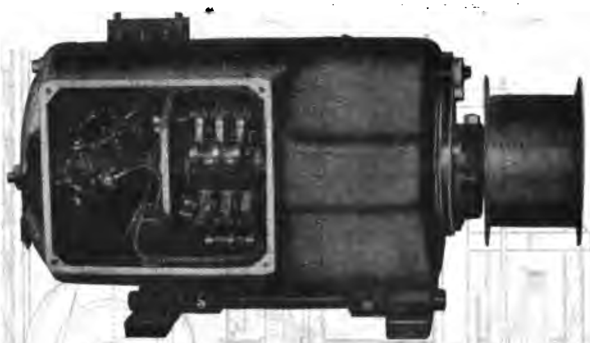


Fig. 1. Newbold 80-Amp. Dynamo, Assembled, with Inspection Plate Removed

meshes with a gear on which are mounted four contacts arranged in a circle. Pivoted in the center of this gear is a pole-changing switch which is rotated through the action of the worm and gear into position to maintain the proper polarity.

Drive: The generator is driven by a belt from a pulley on the car axle to the pulley mounted on the end of the armature shaft.

Suspension: The generator frame is provided with two lugs through which a pivot bar passes. The pivot bar is carried by two bale shoes supported by a wrought iron cradle mounted on the truck.

Belt Tension: The proper belt tension is maintained by a helical spring, tension rod, and adjustable weighted nut.

Regulator: The regulator, main fuse and automatic switch are mounted on a panel placed inside the car. The regulator consists of a solenoid, the core of which is attached to a chain; this chain passing over a sprocket wheel is secured to a weight enclosed in a cast iron box which

acts as a dash-pot. The chain is made fast to the wheel at one point so that any movement of the chain will cause a movement of the wheel.

Attached to the wheel is an arm to which are fastened two sets of carbon brushes, the outer one of which makes

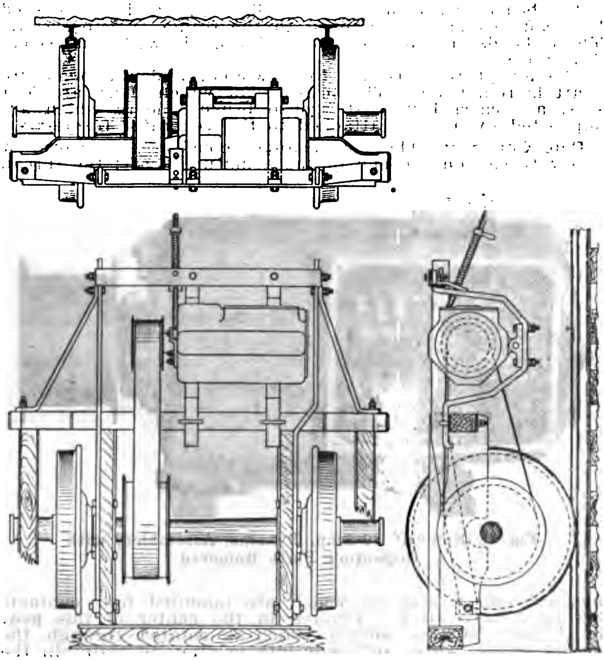


Fig. 2. Outside Suspension of Newbold Axle Generator as Applied to a Standard Four or Six-Wheel Truck

the connection in the field circuit and the inner one of which is in the lamp circuit.

The solenoid has two windings; the first is a series winding through which all of the generator current passes, and the second is a differential winding through which only the lamp current passes, but in a direction opposed to the effect of the series coil. The object of this is to have the gen-

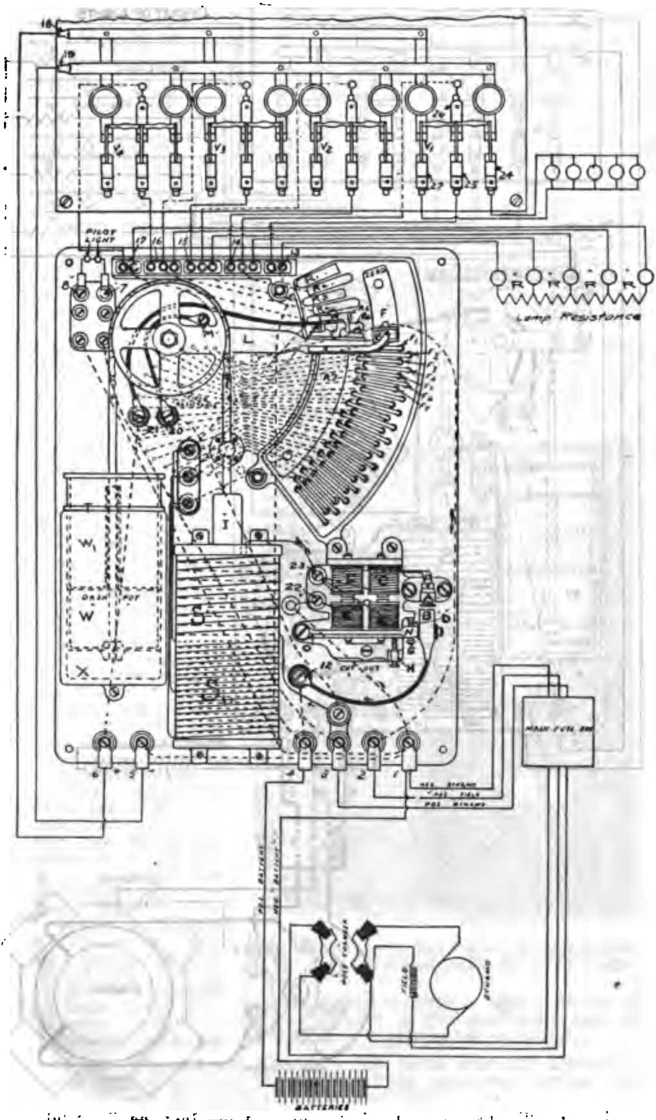


Fig. 3. Wiring Diagram, Newbold System

*BUTTNER SYSTEM WITH ROSENBERG GENERATOR

This system consists of an axle generator designed on the Rosenberg plan, a diagrammatic scheme of which is shown in Fig. 6.

There are two sets of brushes on the armature, which does not differ in any respect from the ordinary armature with a single commutator. The horizontal set of brushes corresponds, so to speak, to the armature of the imaginary exciter. The current flowing through these brushes is induced by a very weak field from the magnet poles, and serves to produce a magnetic field in the armature at right angles to the original field.

As this auxiliary current is dependent on the direction of rotation, it follows that the main field will also change in direction of rotation. The main supply current, which is collected from the vertical set of brushes, tends to produce a field which directly opposes the original flux from the field magnets.

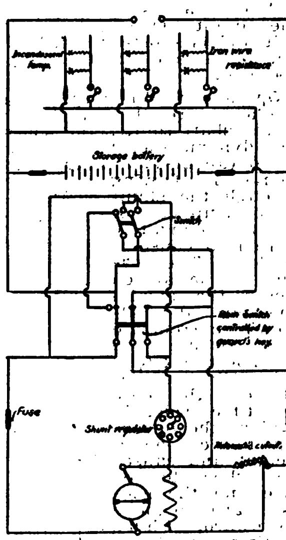


Fig. 6. Rosenberg Axle Generator. Wiring Diagram

The field coils have therefore only sufficient ampere turns to counteract this latter flux and give a small flux in excess capable of generating the current for creating the main cross-field. At full speed, when the machine is giving out its maximum current, the ampere turns of the armature and field coils almost exactly balance one another. On the speed being reduced, the voltage and likewise the current have a tendency to fall. As soon as the current drops slightly, there is a considerable excess of the field ampere turns, which strengthens the main flux in the armature and maintains normal voltage. It is therefore possible for the speed to vary within fairly wide limits with practically no effect on the supply current.

In order to prevent the excitation from varying with changes of battery voltage, iron wire resistance is inserted in the field circuit which prevents an excessive rise of voltage. The resistance will fuse at very high speeds, thus reducing the generator voltage to zero. This serves as a protection to the lamps.

In order to protect the lamps, each one is in series with a special type of resistance which is known as the Buttner lamp resistance. This is a lamp which consists of an iron filament inside a glass bulb, containing gas, the characteristics of which are such that any attempt to increase the current will cause the resistance to rise very rapidly, thus absorbing the voltage fluctuations and maintaining a steady

*Note.—Used in Europe.

pressure on the lamps. This obviates any perceptible fluctuations of light. A reversal in direction of current when the generator voltage falls below that of the battery is prevented by a cut-out device consisting of either an automatic switch or an aluminum cell. The latter is of simple design and consists of aluminum and iron plates in an electrolytic alkali which possesses the property of only allowing a current to flow in one direction; when the current is flowing in the correct direction, hydrogen is evolved on the aluminum plate and no resistance is offered to the current. In the reverse direction oxygen is evolved on this plate which immediately becomes coated with a film of oxide which entirely stops the flow of current.

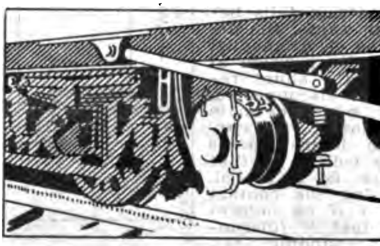


Fig. 7. Method of Suspending Buttner Generator

*BROWN BOVERI SYSTEM

This system is of the axle generator type, the generator being shunt wound and so designed as to generate current of the same direction regardless of the direction of rotation. Fig. 8 shows the wiring diagram for this system. The three magnet windings, *I*, *II*, *III*, are so arranged that *I* and *II* act in the same direction while *III* acts in the opposite direction. The movable coil *O* acts on a contact arm *A*, which short-circuits or connects to the circuit the different positions of the rheostat *G* and the winding *P* of the automatic switch *C*.

When the train starts the generator is excited and current passes through *O*, *I*, and *U*, the position of the brushes being automatically adjusted according to the direction of running of the train. When the generator voltage has risen to a point sufficient for charging the batteries and supplying current to the lamps, the coil *O* is moved so that the contact arm *A* releases the first contact. The armature of the contact switch *C* is now attracted and the generator is connected to the battery.

Current passes now through winding *II* to the battery and strengthens the magnetic flux of the regulator *R* so that the contact arm *A* is moved farther. This happens with increasing speed of the train and in the reversing direction with decreasing speed of the train, while with increasing charge of the battery the voltage at its terminals and at the terminals of the generators is increased and the charg-

*Note.—Used in England.

ing current is decreased. When the battery is fully charged the electromagnet *U*, which operates at a certain voltage, acts on *H* and produces a reduction of the voltage at the terminals of the generator so that an overcharge of the battery is prevented. When the speed of the train decreases, the contact arm *A* is moved gradually into position shown in the diagram in which the winding of *P* of the automatic switch *C* is without current, so that the generator is disconnected from the battery. When the speed of the train falls below a certain value, the armature of the electromagnet *U* returns to its position at rest whereby the shunt resistor at *H* is disconnected.

During the night the main switch *S* is closed. The current of the lamps passes through the coil *Q* so that its armature is attracted, thereby closing the contact *T* (acting on *H* as before) and the contact *K* (disconnecting the winding *II*). When the car stops the lamp resistor *J* and winding *III* are short-circuited by the switch *C*, so that the lamps receive energy directly from the battery. When the train starts the voltage at the terminals of the generator increases and at a certain voltage the regulator *R* causes the switch *C* to act, whereby the generator is connected to the network. The lamps receive energy from the generator through the winding *III* and the lamp resistor *J*, while at the same time there is a charging current into the battery, its size depending on the condition of charge and the intensity of the current of the lamps. To obtain constant voltage at the lamps while the number of lamps lighted is changed, the voltage at the terminals of the generator must vary with the current of the lamps; this variation is obtained by the demagnetizing action of the windings of *III*.

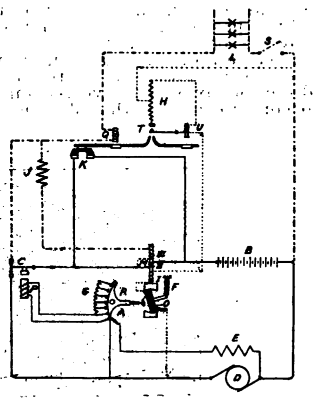


Fig. 8. Diagram of Connections

CONSOLIDATED SYSTEM

TYPE "A"

Generator: The generator is of the bipolar shunt wound type with laminated field poles. The field frame and pedestals are bolted to a cast iron base and the entire generator is enclosed in a sheet and cast iron frame.

The bearings are of the ring oiling type and are carried by the pedestals. The armature is hand wound. Two sets of brushes are carried in cast brass brush holders which are supported by the cast iron frame.

Pole Changer: The armature shaft carries a worm operating a cam, which throws a switch when the direction of rotation of the armature is reversed, as is the case when car is run in a reversed direction. The proper polarity is

thus maintained for charging the batteries regardless of the direction in which the car may be moving.

Drive: The generator is belt driven from a pulley on the car axle, the proper belt tension being maintained by means of a helical spring, tension rod and weighted adjusting nut.

Suspension: The generator on its cast iron sub-base is supported by a rocker bar about which the generator oscillates as a pivot, this rocker bar being supported by two bale shoes which in turn are carried by a wrought iron cradle secured to the truck frame.

Regulator: The regulator consists of a solenoid with a spring balanced plunger to control its operation; the generator field rheostat which is operated by an electric motor connected by means of a worm gear and ratchet mechan-

Fig. 9. Consolidated Axle Generator

ism; and an automatic switch which connects the generator with the lamps and battery at the critical speed, as the car accelerates and for disconnecting it at the same speed as the car decelerates, and a variable lamp resistance operated by the same mechanism that controls the field rheostat.

Operation: The automatic switch has four coils as shown at "C" in the wiring diagram. The shunt coils are wound with fine wire, and the series coils are wound with heavy wire to carry the main generator current. The shunt coils always remain connected across the generator terminals.

When the generator becomes operative and the voltage begins to build up, current flows through the shunt coils, and their cores become magnetized as the voltage rises. When the voltage of the generator reaches the point where it equals that of the battery, the magnetic pull of these coils overcomes their weight and that of the lever and the resistance of the spring, thereby closing the switch and connecting the generator with the battery and lamps. As the speed of the train increases, the current increases until it reaches the point where the magnetic pull on the solenoid core balances the pull of the spring. A further increase of train speed, tending to increase the current generated

will cause the solenoid spring to be overbalanced and throw the upper pawl into gear. The first six teeth of the ratchet wheel are intended to throw into action the cam "W", which through a roller operates the reach rod connected to the arm of the lamp resistance switch "A" and also the solenoid spring lever "Y." At the starting point the tension has been reduced so that the current necessary in solenoid "S" to overbalance the spring would only be about one-

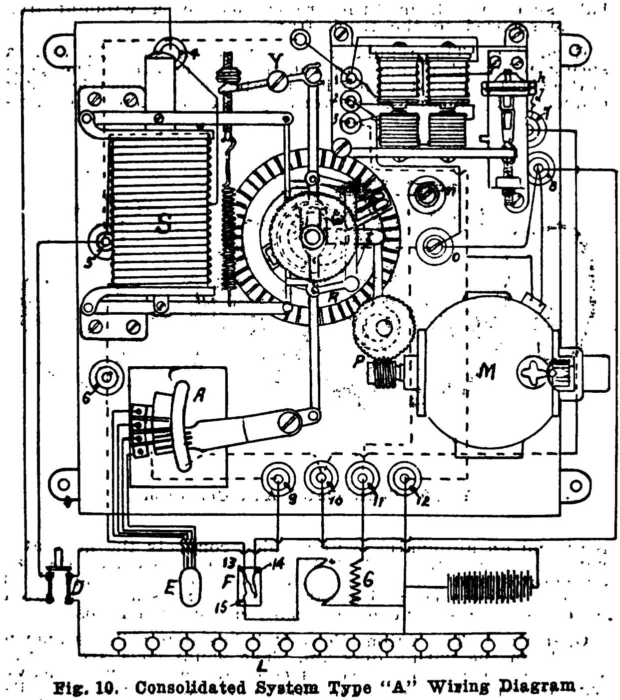


Fig. 10. Consolidated System Type "A" Wiring Diagram

third (1-3) of the required output. When this point is reached the upper pawl operates and switches in part of the lamp resistance "E," and at the same time the lever is moved, thus increasing the tension of the spring.

It now requires more current to overbalance the spring. Consequently, the speed has to increase before further action takes place. If the speed continues to increase, the current will rise until the spring is again overbalanced and allows the pawl to repeat the same operation. This continues until the lamp resistance "E" is all switched in. At this point the lever "Y" has reached a position giving the required tension to the spring. A still further increase in

speed will act in the same manner and will cut resistance into the field "G." A decrease in speed will cause a reversal of the above operation, throwing the gear into the lower pawl, engaging with the front ratchet wheel and cutting out resistance from the field circuit of the generator. The generator current is thus maintained constant at all speeds above the critical. A wiring diagram of this system is shown in Fig. 10.

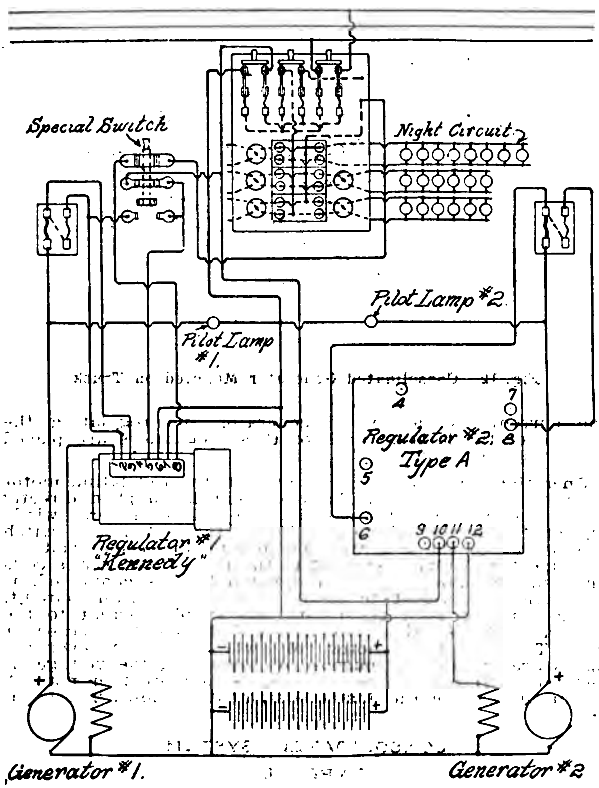


Fig. 11. Wiring Diagram of Double Equipment Kennedy and Type "A" Regulator

CONSOLIDATED SYSTEM
DOUBLE EQUIPMENT

This system is of the usual Consolidated type, but with two distinct axle generators, two regulators, and the usual complement of storage batteries. One regulator is of the "A" type for controlling the current of one of the generators and the other is a Kennedy regulator for controlling

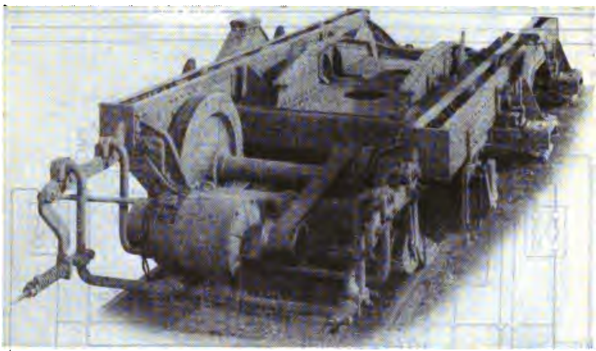


Fig. 12. Consolidated Generator Mounted on Truck

the current of the second generator and regulating the voltage of the lamps. Both of these regulators are placed under the car body.

Operation: When the car is at rest, the regulating motor does not rotate and the lamp current is supplied directly by the batteries through a resistance and the reverse winding of the series windings. When the automatic switch closes, due to the generator picking up at normal voltage, Dynamo "D" supplies current to the lamp fuses, series coils and lamp resistance. When dynamo "D" is connected, it also supplies current to lamps through the same circuit. While running, both generators will supply current to the batteries whether the automatic switch "SW" is closed or not. The regulating motor "M" will rotate whenever the lights are on, for the purpose of regulating the voltage, it being immaterial whether the car is in motion or not. A wiring diagram of the double equipment is shown in Fig. 11.

CONSOLIDATED SYSTEM
TYPE "D"

Generator: The generator is of the four-pole, interpole, shunt wound type, with cast steel frame, and has a rated continuous capacity of 45 amperes at 60 volts.

The bearings are of the ring oiling type and are carried in the heads which are secured to field frame by cap screws. Large oil wells are provided which are fitted with overflow pipes to prevent overfilling.

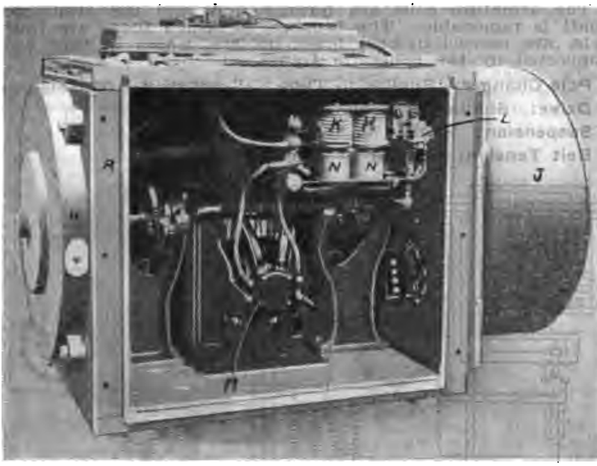


Fig. 13. Kennedy Regulator

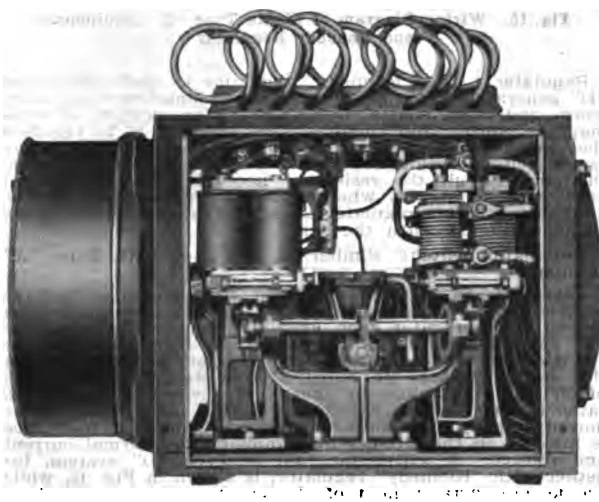


Fig. 14. Kennedy Regulator

The armature coils are form wound, and the armature shaft is removable. The brushes, of which there are four sets, are carried in cast brass holders, which in turn are supported by the generator frame.

Pole Changer: Similar to Type "A" but of a larger size.

Drive: Similar to Type "A."

Suspension: Similar to Type "A."

Belt Tension: Similar to Type "A."

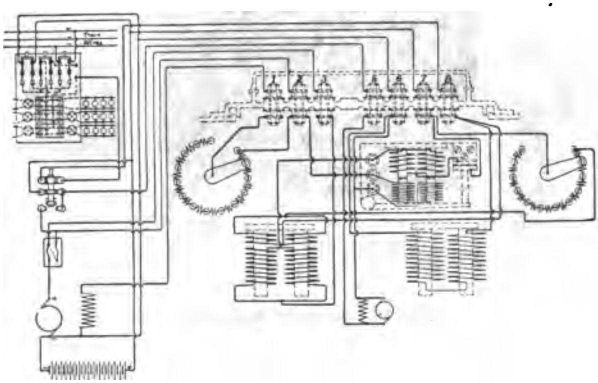


Fig. 15. Wiring Diagram of Single Type "D" Equipment and Kennedy Regulator

Regulator: The "Kennedy" regulator is used with Type "D" generator. This regulator is a combination of a motor, worm and gear, shafts, levers, pawl and ratchet, electro-magnets, spring and rheostat. Its function is to regulate the current to the generator fields, so as to have the generator deliver the desired output and also to introduce into the lamp circuit the resistance necessary to give normal voltage at the lamps whether the battery be charging or discharging. This regulator is incased in a dust-proof box suspended underneath the car.

Automatic Switch: Similar to that used with Type "A" equipment.

Operation of Regulator: When the generator voltage reaches a predetermined point, the automatic switch closes; the generator then supplying current to the lamp and battery circuits. If the lamps are turned on and the speed of the generator is sufficient to generate a current of the normal voltage to supply the system the regulating motor will rotate and by means of several shafts, gears, ratchets and pawls, will cause the rheostat arm to be moved step by step until the proper amount of resistance is inserted in the circuits for supplying the normal current and voltage. A wiring diagram of Type "D" system, together with "Kennedy" regulator, is shown in Fig. 15, while the general arrangement of the generator on the truck is shown in Fig. 12.

CONSOLIDATED AUTOMATIC RECORDING DEVICE

The Consolidated Company also furnish an automatic recording device which indicates on a roll of paper the amount of current generated, etc., for a period of thirty days. The regulator controls the output of the dynamo in such a way that the battery will be charged at its normal rate up to the point where it is fully charged. Then to prevent the battery being overcharged, the current is automatically cut down to any desired quantity or cut out entirely, whichever is desired, until such time as the battery needs more charging or the lamps are turned on, the idea being to prolong the life of the belt by reducing the amount of work of the generator when current is not required, and prolong the life of the battery by preventing overcharge.

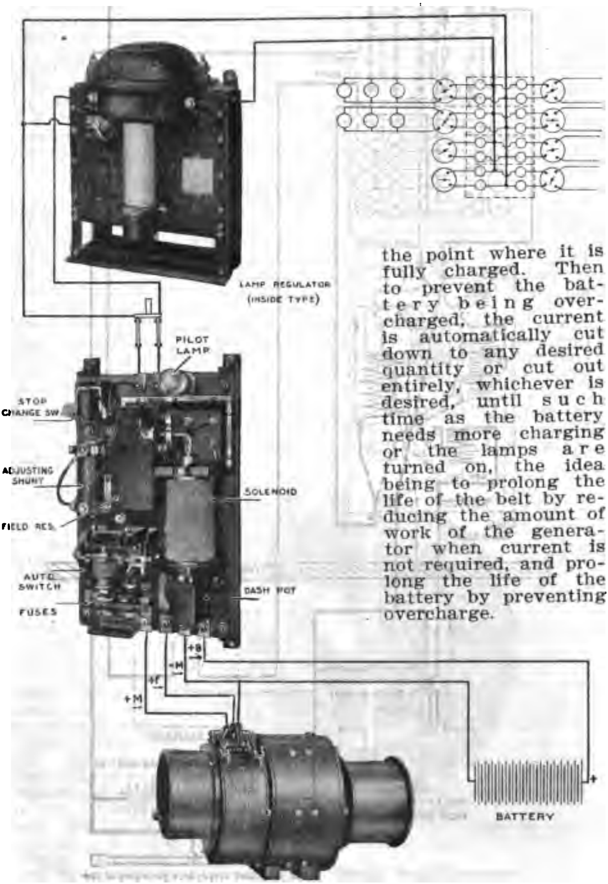


Fig. 16. Showing the Wiring for Connecting the Consolidated Axle Light System Type "D" Dynamo with "L" Regulator

CONSOLIDATED TYPE "L" REGULATOR

The Type "L" regulator consists of a solenoid connected in series with the generator. The solenoid core operating

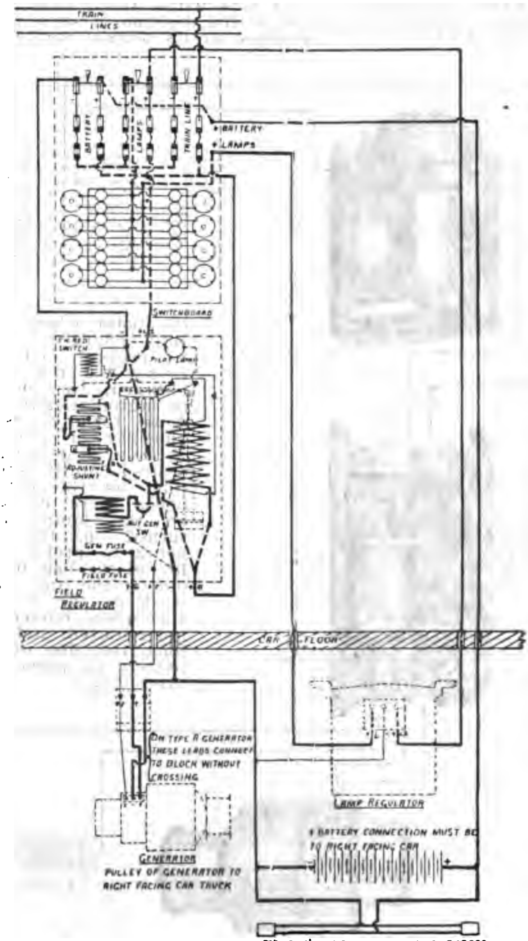


Fig. 17. Wiring Diagram of Complete Equipment with "Pullman" Switchboard. Type "D" Dynamo with Type "E" Regulator

a rocking contact arm, the contact operating over a series of bars connected to a continuous resistance consisting of metallic grids proportioned to suit the field of the generator.

An adjustable shunt is provided by varying which the amount of current from the generator to lamps can be set at any desired value within the range of one-third to full lamp load. A stop charge switch is also employed for cutting of the generator current when the battery is fully charged.

The stop charge switch may be adjusted by varying the air gap between the armature and its magnet by means of a graduated cam. The winding of the switch coil being connected across the generator leads, while a second shunt coil is added to the governing solenoid, that when the first coil closes the switch at some predetermined value the second shunt coil adds additional strength toward drawing up the solenoid core and inserting additional resistance in the generator field, thereby reducing the generator output.

GOULD SIMPLEX SYSTEM

Generator: The generator is a multipolar shunt wound machine of the enclosed type, having a cast steel field frame with laminated pole pieces. The bearings are of bronze, the oiling being accomplished by packed oil waste or rings as desired. The commutator end of the generator is provided with hand holes and covers so that the branches are readily accessible.

The leads to the generator brushes and fields and the external leads from the generator are brought to a terminal block in the top casing of the commutator end of the generator. The pole changer is mounted on the shaft directly under the terminal block.

Pole Changer: The pole changer, a phantom view of which is shown in Fig. 18, is of the mechanical operated type, comprising a double pole, double throw switch interposed between the brush leads and the external leads of the generator. The switch throwing mechanism comprises an excentrically drilled weight pivotally mounted on a carrier and the latter mounted on the armature shaft. The weights have forward and rear projections to engage corresponding projections on front and rear switch blades when direction of rotation is reversed. When the switch is tipped the throw is completed by a spring toggle preventing further contact with the tipping mechanism while the direction of rotation is again reversed. In the illustration

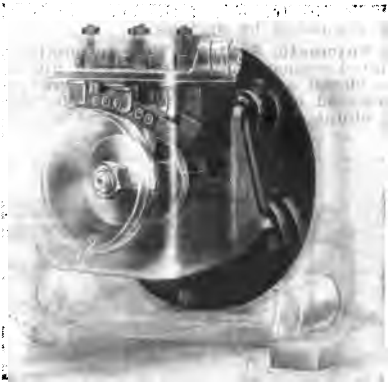


Fig. 18. Gould Pole Changer

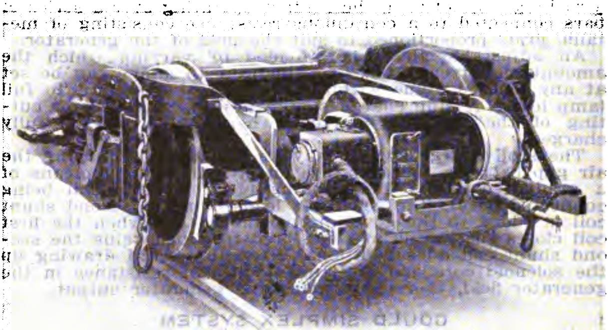


Fig. 19. Gould Drop Type Suspension

Fig. 18, the rear projection of the weight is about to throw the switch to a position corresponding to right hand rotation, should the direction be reversed, the front projection of the weight coming in contact with the lug on front switch blade, will throw the switch in the opposite direction, thereby maintaining the proper polarity of the generator leads.

Generator Suspension: This generator is suspended by means of the Link Type or the Drop Type Suspension. Views of these are shown in Figs. 19 and 20, in either of which provision is made for alignment of the generator shaft with the car axle and the generator and axle pulleys; while the tension of the chain or belt drive after being set is regulated by springs.

Automatic Switch: The automatic switch is of the laminated copper contact type with auxiliary carbon brake and is closed against the action of gravity by the lifting of its solenoid core. There are two windings on the solenoid, one a shunt coil across the generator mains, the other a heavy

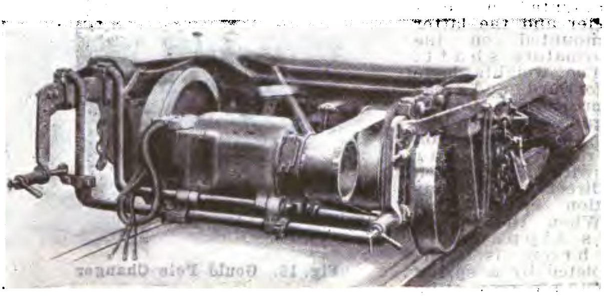


Fig. 20. Gould Link Type Suspension

series coil connected in series with generator mains. When the generator voltage reaches the proper value the shunt coil becomes sufficiently energized to raise the plunger and close the switch. The series coil is then energized and reinforces the action of the shunt coil, assisting in holding the contacts, or switch, closed. Should the generator speed be decreased and the voltage drops to that of Battery Voltage the latter tends to discharge through the series coil in an opposite direction, thereby neutralizing the fall of the solenoid and gravity reinforced by the switch springs causes the switch blades and generator current to open. On top of the solenoid plunger is a metal disk and laminated copper brushes which serve to short circuit the series coil of the regulator simultaneously with operation of the switch. This prevents the current due to the lamp load from exerting an effort to raise the solenoid plunger of the series coil of the regulator and increasing the resistance in the field circuit, which would tend to prevent the building up of the generator.


Fig. 21. Simplex Regulator and Distributing Panel

Generator Regulator: The generator regulator is affected through the compression of carbon pile disks in the generator field circuit. A variable compression of the disks is obtained by the movement of two lever arms, one of which is actuated by the solenoid plunger of a series coil in the battery branch circuit, the other being actuated by the plunger of a shunt coil connected across the generator mains. So long as the battery is not fully charged the variable compression on the carbon disks obtained through the lever actuated by the plunger of the series coil, maintains the generator current practically constant, by increasing or decreasing the resistance of the carbon pile should the current tend to increase or decrease from normal.

When the battery becomes fully charged, as determined by its attaining a definite limiting voltage, the shunt coil of the regulator becomes sufficiently energized to lift its plunger, thus decreasing the compression

of the carbon pile resistance through the movement of the other lever arm. Under this condition the plunger of the series coil is no longer sustained, as the current to the battery is reduced. The control of the field strength, and consequently the voltage, then results from the shunt coil. The current output of the generator is reduced to the value of the current required for the lamps that are burning, the voltage thus corresponding to that of the fully charged battery.

The shunt coil also acts as a prevention against excessive generator voltage, should the battery circuit be broken

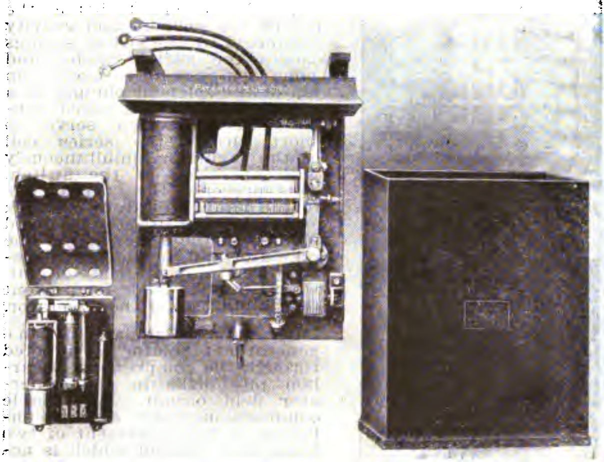


Fig. 22. Type "B" Gould Lamp Regulator and Multiplier

for any reason. In this event the generator would supply current for the lamps when the speed of the car is at or above the minimum limiting speed.

The solenoid plungers are restrained from oscillation by means of dash-pots, while to ensure the building up of the generator in case of loss of residual magnetism a resistance unit is connected between the battery and armature circuit, which permits a small amount of current to flow across the armature, breaking down any resistance that may exist.

Lamp Regulator: Lamp regulation is obtained by pressure being exerted upon a series of carbon disks; this pressure being varied inversely with the voltage of the generator. The variable pressure is obtained by a lever arm actuated by a solenoid plunger, the current in the solenoid coil being controlled by an auxiliary regulator, also of the carbon pile type, acting as a multiplier. Thus a very slight increase in voltage of the lamp circuit results in a decided increase in lifting effort on the main plunger, thereby maintaining the lamp voltage and candle-power at approximately constant values regardless of any variation in gen-

erator and battery voltage. The regulator is always in the circuit when the lamps are burning, but the carbon pile resistance is shunted gradually as the battery discharge proceeds.

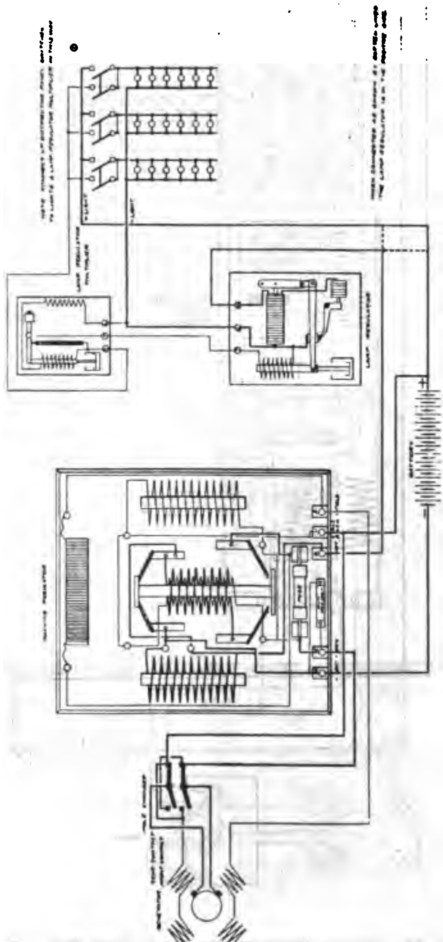


Fig. 23. Wiring Diagram Gould System

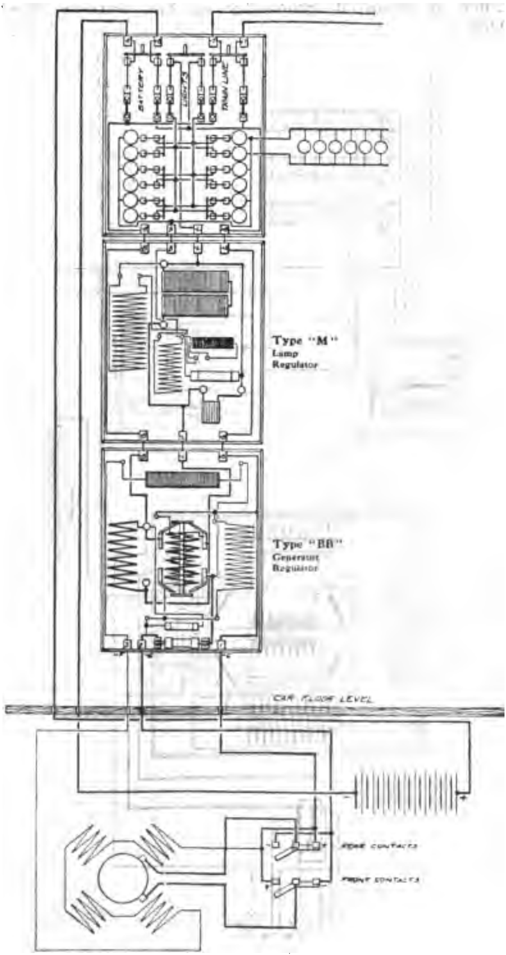


Fig. 24. Wiring Diagram for Panel Type Regulators

Fig. 24A. Gould Connector for Connecting Car Wiring and Generator

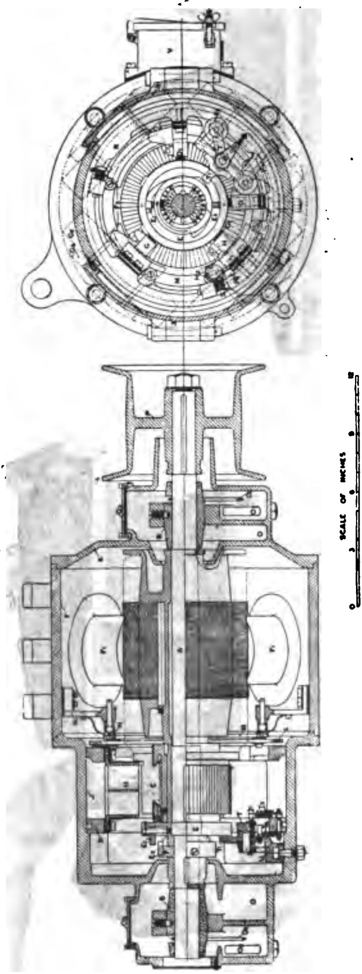


Fig. 25. Sections Showing all Parts of a Series 6 Machine Leitner Generator

LEITNER SYSTEM—ENGLAND

Generator: This axle generator is belt driven, and is suspended underneath the car at an angle with the vertical, the weight of the machine tending to keep the belt tight. In the wiring diagram it is shown as a bi-polar machine but as actually constructed it has four poles and four sets of brushes, two of which are for the variable excitation.

The frame of the dynamo is of cast steel, two large doors being provided for access to the brushes. The pole pieces are laminated. All terminals are brought out to a specially fitted board outside the frame. The bearings are of the ring oiling type. The commutator segments are of:

Fig. 26. The "Auto-Switch" or Cut-Out

Pole Changer: The pole changer is composed of the reverser and brush rocker which together act to automatically give the correct angle of lead to the brushes depending on the direction of rotation. The action of the reverser is positive although an anti-shock device transmits the power from the shaft. It is only brought into action momentarily upon a reversal of the direction of the train.

The brush rocker is composed of the brush holders and reversing trolley mounted on a cast iron ring. The brush holders are brass boxes with depressing levers controlled by adjustable springs in connection with toothed adjusting wheels. Electrical connections are made through spring collecting pins and rings.

Auto-Switch: The auto-switch, or cut-out, has the function of automatically disconnecting the storage battery from the dynamo whenever the voltage of the latter falls below that of the former. It also has the function of connecting the battery and the dynamo when the generator voltage is greater than that of the battery.

It consists of a pivoted H armature carrying a switch arm, which is free to rotate through an angle of 30°. The rotation of this arm is produced by the attraction of the two polar projections.

The whole switch, together with the main fuse, is enclosed in a cast iron box.

Operation: As shown in the diagram of connections, the output is adjusted by means of a series of resistances connected in the shunt field circuit, and its function is to regulate the generator output in steps of 45, 30, 25 and 20 amperes.

As shown in the wiring diagram there is an extra pair of brushes in the shunt field circuit which bear upon the

armature. These brushes are so located that when the armature first starts to revolve one brush is positive and the other is negative and they assist the main brushes in sending the exciting current through the field coils, building the field up rapidly. As the speed of the armature increases the field flux is distorted, gradually reducing the voltage between the auxiliary brushes to zero and it is then reversed. With increased speed this difference in potential in a direction opposed to that of the main brushes gradually chokes down the current in the shunt field. It is claimed that this keeps the dynamo voltage practically constant inasmuch as the voltage of a generator depends upon the field strength and speed of rotation.

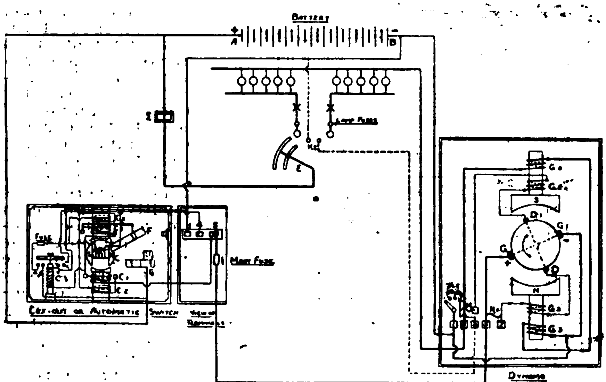


Fig. 27. Wiring Diagram of Leither System

The other set of field coils are in series with the lamp load and do not carry current until the lamp circuit is closed by the main switch. They are not strictly necessary but aid in assisting the excitation of the dynamo independently of the residual magnetism.

In a bi-polar machine the auxiliary brushes form an angle of about 20° with the vertical, and about 10° in a four pole machine.

As stated above the cut-out has the function of automatically cutting in and cutting out the generator. Its operation is dependent upon the difference of voltage between the battery and generator.

The coils of the small relay shown at the left of the cut-out switch are across the dynamo terminals. When the voltage of the generator reaches a certain point, say 15 volts, this relay attracts its armature, thereby permitting the battery current to flow through the shuttle armature holding the contact arm and also through the fine windings on the pole pieces. This causes the magnetism of both the armature and pole pieces to be such that the contact arm is forcibly held out.

As the voltage of the dynamo rises the current through the fine windings diminishes until finally, when the voltage of the battery and generator is equal, this current becomes

zero. A further rise of generator voltage reverses the direction of this current, and, as the battery current through the shuttle armature always remains in the same direction, the reversed magnetism of the pole pieces causes the armature to rotate and the arm to close the circuit.

The fine windings on the pole pieces are now short-circuited. The heavier series windings then come into action. They are wound in the same direction as the fine windings

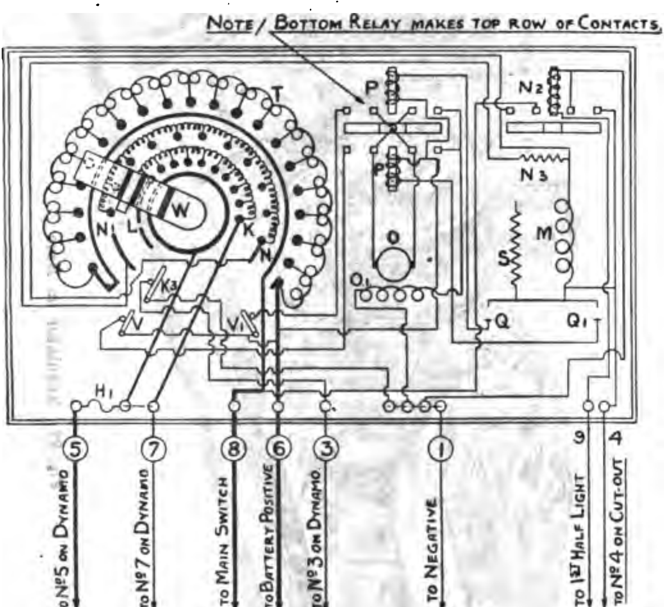


Fig. 28. Leitner Regulator

and as they carry practically all the generator current they tend to hold the contact arm and keep the circuit closed as long as the dynamo voltage remains above that of the battery. When it drops these series coils allow and somewhat assist the spring attached to the contact arm to open the circuit, after which the fine windings on the pole pieces come into action and assist the spring.

The regulator consists of what is termed as a "voltage balance" and a small reversible motor actuating a contact arm over three sets of resistance studs, thereby inserting or withdrawing resistance in three separate circuits. The following action is claimed for this regulator.

When the lamps are burning the voltmeter or controlling coil is in multiple with the lamp circuit. The motor is then actuated by this coil and rotates the contact arm to

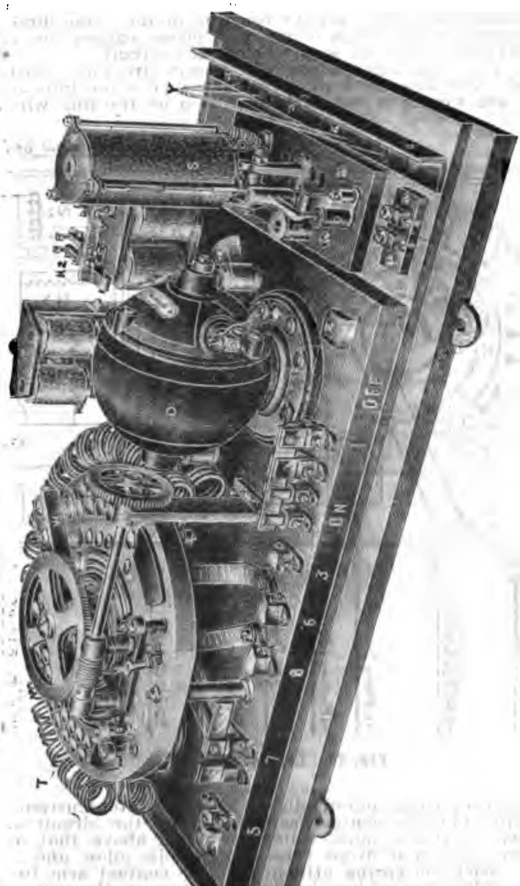


Fig. 29. Regulator on Base

such a position on the outside ring of studs that the resistance controlled by these studs, which is in the lamp circuit, will absorb the difference between the lamp voltage to which it is adjusted and the battery or generated voltage. The contact arm of the voltmeter is then in equilibrium. An increase or decrease of voltage will cause this arm to make one of two contacts and this will cause the motor to drive the regulator to a correcting position.

If the dynamo is in circuit the strength of one-half the field is altered at the same time that the resistance of the lamp circuit is changed. This is accomplished by the addition or withdrawal of resistance in the field circuit through the inner ring of studs. The two actions effect a double regulation, the generator voltage being altered simultaneously with the resistance of the lamp circuit.

If the lamps are not burning and the generator has only the battery load, the voltmeter coil is in parallel with the battery instead of the lamps. As this controlling coil causes the motor to rotate the regulator, the action of the contact arm on the middle ring of studs inserts resistance into controlling or voltmeter circuit. Thus, as the battery voltage rises during charge, the voltmeter, by its own action, raises the voltage to which it will respond and at the same time raises the dynamo voltage to meet the requirements of charging the battery. As the battery nears a fully charged condition, the regulator opens the field circuits upon which the cut-out acts and the dynamo is put on open circuit. If lamps are then switched on, the added resistance in the voltmeter circuit is short-circuited, the regulator is brought to lamp voltage adjustment, and the dynamo is cut in, providing its speed is high enough.

*MATHER AND PLATT SYSTEM

This system is of the axle generator type, consisting of the generator mounted for axle drive, an accumulator, switches and regulator. Fig. 32 gives a diagram showing the wiring connections.

When the train is at rest the solenoid switch, SS, is in the lower position and the batteries, BB, feed the lamps direct through the main switch, ES. The generator is cut out of the circuit at the point D.

As the speed of the generator rises there is a gradual increase in the current flowing in the shunt winding of the solenoid switch, SS, until, when the generator voltage equals that of the battery, the plunger of the solenoid is pulled up, closing the circuit at DC and breaking it at LR. This takes place at a train speed of six to eight miles per hour. The generator at this point is supplying only a very small current, thus preventing the burning of the switch contacts.

The output of the generator rises after "cutting in" until at about 18 miles per hour it is giving practically its maximum output. The output remains practically constant above this speed.

As the speed decreases the generator output decreases until at about five miles per hour it reaches zero. Any decrease below this point tends to reverse the current through the generator, the series coil of the solenoid demagnetizes the solenoid and the generator is "cut out;" at the same moment the resistance LR is short-circuited and the batteries are connected directly to the lamp circuit.

*Note.—Used in England.

The output of the generator is controlled by the insertion of resistance into the shunt field. This resistance is controlled by the same switch that controls the lights and the amount is dependent upon the number of lamps burning.

The regulation is controlled entirely in the generator itself. The arrangement of the generator is shown in Figs. 31a and 31b. The armature and commutator are similar to the

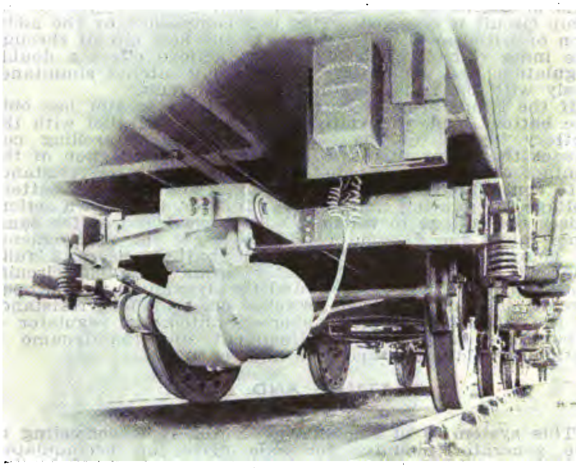


Fig. 30. Dynamo Fitted Under Coach

ordinary drum wound machine. The brushes, bb, which in a normal machine would supply current to the external circuit are short-circuited and a second pair of brushes, BB, at right angles to the first pair, constitute the main working brushes, supplying current to the external circuit. The generator is of the shunt wound type, the shunt field ff being connected across the armature terminals in the diagram.

The field windings establish a flux in the field magnets passing vertically through the armature as indicated by the letters, SS, NN, Fig. 31. The rotation of the armature in this magnetic field induces currents in its conductors which circulate through the aid brushes bb. The field windings ff are relatively small since a very small flux is sufficient to produce a large short-circuit or aid current.

These short-circuit or aid currents produce a flux through the armature, at right angles to the primary flux, which circulates around the pole pieces and armature as indicated by SS, NN, and does not traverse either the pole limbs or yoke which carry the primary flux. The rotation of the armature in this secondary flux induces a difference of potential between the brushes, BB, and sends current into the external circuit.

If, for the sake of clearness, the currents flowing in the armature be considered as existing in two independent windings, it will be observed that whereas the currents flowing through the aid brushes bb produce a flux at right angles to the primary flux, and therefore producing no effect on this latter flux as regards magnitude, the currents flowing through the main brushes, BB, produce a flux exactly opposed to the primary flux and accordingly diminishing it in exact proportion to the strength of the current in the external circuit.

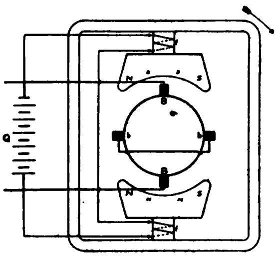


Fig. 31a

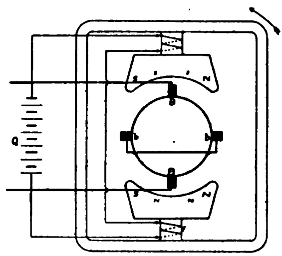


Fig. 31b

It follows, therefore, that for a certain value of the external current the ampere-turns of the armature will exactly correspond to the ampere-turns of the primary exciting winding, and, being equal and opposite, the resultant flux will be zero. As without a primary flux the dynamo would cease to generate current, it is clear that the limiting value to the external circuit which the dynamo can produce is that current which makes the armature ampere-turns equivalent to the field ampere-turns. Further, as a very small excess of field ampere-turns over armature ampere-turns is necessary to produce the current in the aid brushes which set up the working field, a very small diminution in the current in the external circuit is sufficient to produce this working flux. A variation of 12% in current is obtained through a range of train speed of from 21 to 65 miles per hour.

Reversal of the direction of rotation of the armature reverses the direction of the aid current, but leaves the current in the primary exciting windings unchanged. The horizontal armature flux is, therefore, reversed in direction and this, together with the change in direction of rotation of the armature, causes the direction of the current in the external circuit to be the same as before.

The efficiency of this generator is approximately the same as that of an ordinary generator of the same output, the commutation losses being slightly larger while the excitation losses are smaller. Both sets of brushes work sparklessly when the machine is running in either direction and over any range of speed within the bounds of mechanical safety.

REFERENCES

AM Ammeter.
BB Batteries.
C Positive terminal of cells.
D' Positive terminal of dynamo.
D Dynamo.
DF Dynamo fuse.
ES Exterior main switch.
FM Field magnet winding.
FL Full lights.
HL Half lights.
NL No lights.
LR Lamp resistance.
MF Main fuse.
SR Shunt regulator.
SS Solenoid switch.
TS Emergency switch.

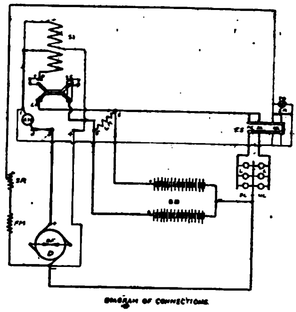


Fig. 32

SAFETY
TYPE "F" SYSTEM

Generator: The generator, which is made in 2.6 and 4-kw. size, is a multipolar shunt wound machine, with one piece steel magnet frame and interchangeable cast iron heads for bolting to commutator or pulley ends of magnet frame. The bearings are of the bushing type, made of bronze, and alike for both ends of the generator. The bearings are obtainable in either the waste packed or ring oiling type, the oil being added through a filling tube in the side of the head and which acts as an overflow, the low lip of the filling tube determining the proper level of the oil.

The armature is form wound with fireproof insulated wire, the coils being held in slots by hard fibre wedges. The brushes are eight in number (two to each holder), each having separate trigger with spring tension to maintain the contact with the commutator. Each brush has the usual copper shunt to maintain a good contact with the brush holders.

Pole Changer: The current direction is maintained constant by rotating the brushes through an angle of about 90° whenever the direction of rotation of the armature is changed. The four brush holders are mounted on an insulated supporting ring which acts as an outer race of a ball bearing, which is slipped over a finished hub on commutator head and held in place by a snap spring ring. The brush rocker has two stops about 90° apart, with luggage projections cast on head. While running the friction of the brushes on the commutator holds the rocker firmly against one of those stops. Reversing the direction of rotation causes the brush rocker to be turned over against the other stop, changing the position of the brushes, but maintaining the same polarity as before.

Generator Suspension: The generator is supported as shown in Fig. 33. The horizontal shafts by which the generator is suspended pass through holes in the projections cast on the field frame, these shafts in turn being supported by links carried by movable pieces resting on heavy, horizontal bars. The bars in the case of steel trucks are passed through holes in end of truck frame and then bolted.

The dynamo is mounted on the car truck outside the end sill and is driven by a belt from a pulley on the car axle. Fig. 33 shows the general arrangement as applied to a standard form of cast steel truck. The heavy horizontal

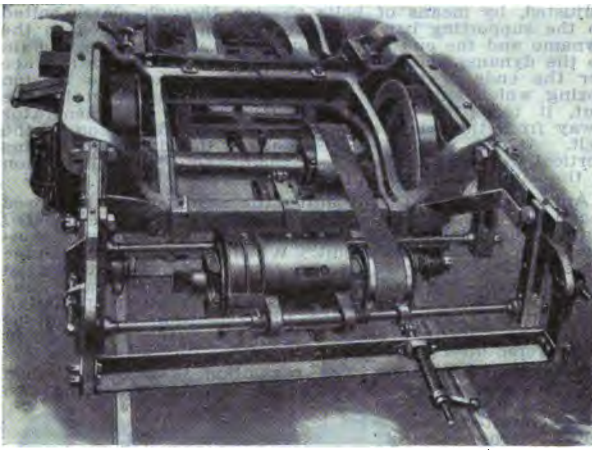


Fig. 33. Dynamo Suspended on Six-wheel Steel Truck

steel bars from which the dynamo is suspended pass through holes in the end of the steel frame of the truck and are bolted to the frame. The ends of these bars are turned down and securely clamped together by an angle iron, which serves as a brace and supports the tension rod. These bars are further strengthened to prevent lateral motion by braces bolted to the end of the truck. The dynamo is suspended on two horizontal shafts passing through two lugs on each side of the dynamo frame, the two lugs having a long bushing between them. These shafts are supported on each end by links carried by movable pieces resting on top of the horizontal bars. These pieces are adjusted by means of screw bolts, to give proper alignment with the car axle, and are held securely, after being

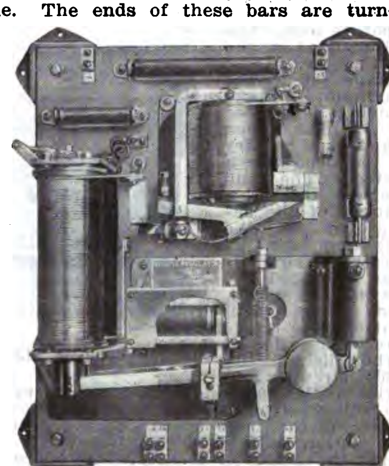


Fig. 34. Type "F" Dynamo Regulator Panel

adjusted, by means of bolts passing through plates bolted to the supporting bars. A safety chain is attached to the dynamo and the end of the truck, and another safety chain to the dynamo and the angle iron which serves as a brace for the ends of the suspension bars. When the tension spring which surrounds tension rod is compressed by the nut, it tends to pull the horizontal bars and generator away from the truck and give the required tension to the belt. As the vertical center line of the dynamo remains vertical with any movement of the dynamo, the belt tension is the same with either direction of drive.

Automatic Switch: The automatic switch is of the closed magnetic type, having a fine or shunt winding connected across the generator circuit, and having windings connected in series with circuit. When the generator voltage rises to the proper value the shunt winding is energized sufficiently to raise the solenoid and close the heavy laminated contact when the series coil there maintains a firmly closed contact. When the generator voltage drops to that near Battery Voltage, the Battery Current, being in the reverse direction, causes the switch to "kick out."

Generator Regulator: The regulation is by the Carbon Pile Resistance Method, the dynamo regulator having two coils, one a voltage coil connected directly across the generator leads and a series coil connected in the main circuit. Each coil acting independently on a separate arm. The pull exerted on the plunger of the voltage coil at the maximum voltage which it is desired to impress upon the storage battery is balanced by a spring. The pull exerted on the plunger of the series coil at the maximum dynamo current desired is also balanced by the pull of a spring. The voltage coil controls the pressure on a series of carbon discs in the field circuit and varies their resistance, as may be necessary, to prevent the voltage from rising above the maximum for which it is set, as the train speed changes. The series coil comes into action only if the output tends to exceed that for which the regulator is set, when a projection on the lever engages with a second lever and the series coil then assists the voltage coil in controlling the carbon pressure.

Fig. 35. Type "F" Lamp Regulator Panel

When the dynamo is at rest, the arm connected with the plunger of the series coil rests against a stop at the top of the coil and the field resistance carbons are tightly com-

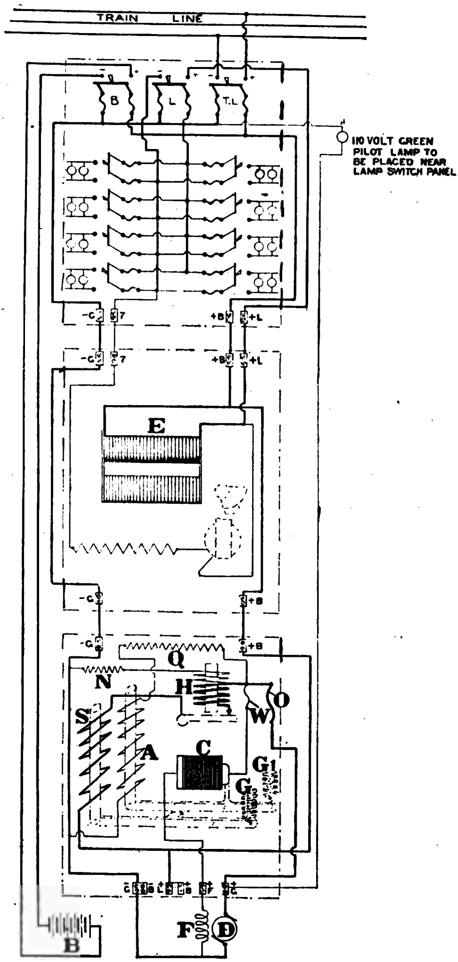


Fig. 36. Type F Wiring Diagram Lamp Regulator in Car

pressed by the pull of the spring, so that their resistance is low. As the armature begins to revolve current flows through the field coils and builds up a voltage which energizes the lifting coil of the main switch.

As soon as this voltage is the same as the battery voltage the main switch closes, cutting into circuit the series coil of the main switch which holds the switch firmly closed.

Current now flows from the positive dynamo terminal, through the series coil of the main switch and the series regulating coil to the lamps and storage battery and back to the negative dynamo terminal.

As the train speed increases and the dynamo is able to give its full output, the control is by means of the series coil provided the full output of the dynamo can be used for charging the storage battery or for the lamps. As the storage battery becomes charged and its voltage rises, the current tapers off so that the full output of the dynamo is no longer required, and the series coil arm moves out of engagement with the voltage coil arm and rests against its stop. The voltage coil then prevents the voltage from rising above the voltage for which the regulator is set.

If a lead battery is charged at a constant voltage of 2.5 per cell, the charge will start at a high rate and automatically taper to nearly zero as the battery becomes full corresponding to a stop charge. In a thirty-volt equipment, having sixteen cells, the battery will be protected from overcharge if the dynamo gives 40 volts and the battery will be charged in the shortest possible time. If, however, the battery is almost discharged and there is a heavy lamp load, the demand on the dynamo would be greater than its safe capacity, so that the series coil is necessary to limit the current the dynamo can give. The action of the generator regulator is to cause the dynamo to give its full capacity at all times if it can be used, and to protect the battery from overcharge.

Lamp Regulator: The lamp regulator is shown in Figs. 34 and 35, the general idea being to maintain the voltage on the lamps constant by varying in the proper amount a carbon resistance in series with the lamps.

The carbons are compressed by an adjustable spring connected to a link acting through a toggle. The pull of the spring is opposed by the pull of the electro-magnet, which is connected directly across the lamp mains and is so designed that the armature will stay in any position throughout its stroke when the lamp voltage is right.

When the lamp voltage is high the magnet becomes stronger and pulls the armature down against the pull of the spring and reduces the pressure upon the carbons, increasing their resistance and bringing the lamp voltage back to normal. If the lamp voltage is low, the magnet becomes weakened and the spring pulls the armature back until the toggle exerts sufficient pressure on the carbon discs to decrease their resistance and bring the voltage to normal.

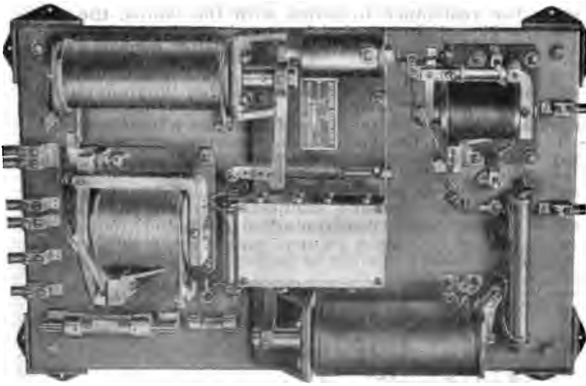


Fig. 37. Type "D" Dynamo Regulator Panel

SAFETY
TYPE "D" SYSTEM

Dynamo Regulator: When the dynamo is at rest the carbon discs in the field are tightly compressed by the pull of a spring so that the resistance is very low. As soon as the armature revolves, current is generated which flows through the field coils which energizes the lifting coil of the main switch. When the voltage is the same as the battery voltage, the main switch closes, connecting into the circuit a series coil, which holds the switch firmly closed. As the current rises a pull is exerted on the plunger of a solenoid magnet and the pressure on the carbons is decreased, thereby increasing the resistance in the field circuit.

Lamp Regulator with Relay: The regulator keeps the voltage on the lamps constant, by varying the pressure on

Fig. 38. Type "D" Lamp Regulator Panel with Relay

a carbon disc resistance in series with the lamps, the pressure on the discs being varied by an electromagnet working through a toggle. The electromagnet being operated by a relay.

This company also manufactures another lamp regulator, the action of which is to keep the voltage on the lamps constant by varying in the proper amount a carbon resistance in series with the lamps, the pressure on the disc being varied by an electromagnet working through a toggle. The solenoid connected across the lamp circuit acts as a master controller or pilot, and varies the pressure on another set of small carbons connected in series with the windings of the large electromagnet.

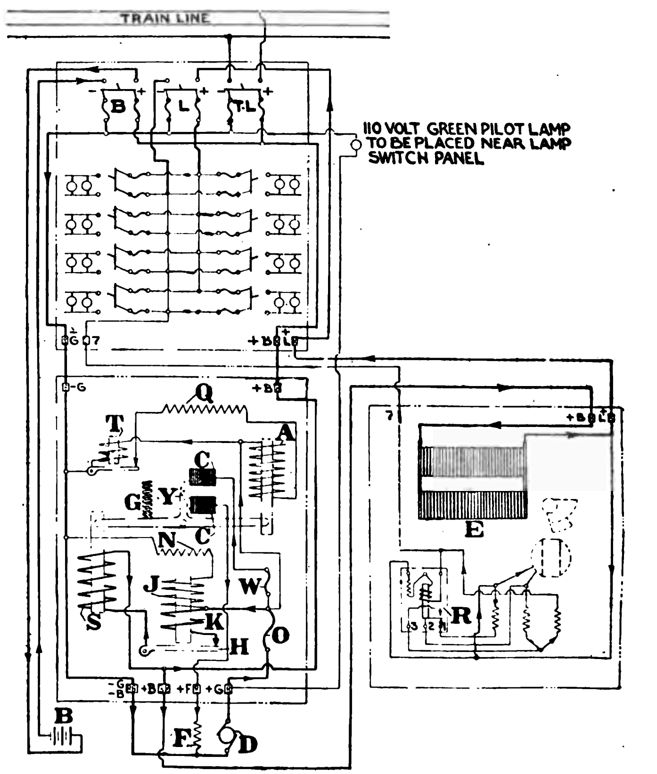


Fig. 39. Wiring Diagram Lamp Regulator with Relay Under Car

STONE SYSTEM
STONE AXLE DYNAMO

Generator: The generator is of the two-pole shunt wound type with a rated continuous capacity of 18 amperes at 25 volts.

The bearings are of the ring oiling type and are carried by supports secured to generator frame. The oil wells have an overflow pipe. The armature is of the old Gramme ring hand wound type.

Two sets of brushes are carried in cast brass holders secured to the generator frame.

The polarity is changed by means of a rocking arm and friction gear. To change over the direction of the rocking arm, two plungers press against lignum-vitae blocks on rear end of the rocking arm by means of a spring engaging it and carrying it around to slots. These plungers fly out

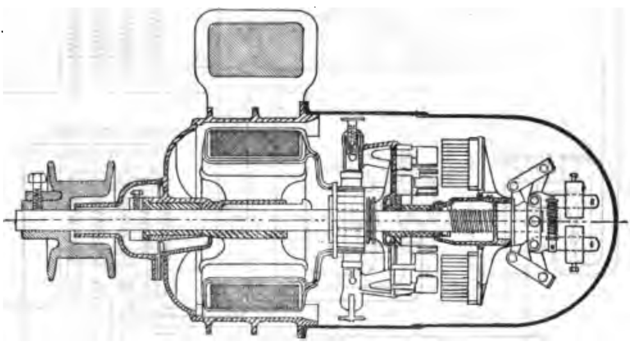


Fig. 40. Stone Axle Dynamo—Longitudinal Section

free from the rocker arm when the centrifugal force, due to the rotation of the armature shaft, is great enough after the arm is pushed home into the contacts.

The generator is suspended by means of an adjustable link in such a manner as to leave the generator free to swing. The belt is then adjusted to pull the generator out of the vertical position in which it would naturally hang, thus putting a tension on the belt sufficient to absorb power equivalent to the amount of current required at the speed for which the belt tension is adjusted. It is obvious, therefore, that increasing the speed will cause the belt to slip.

No regulator is used as it is supposed that the cushioning effect of the batteries in connection with a small resistance inserted in the lamp circuit and the slipping of the belt is sufficient to maintain the voltage within such limits that the variation of the candle-power of the lamps is not annoying.

The automatic switch is of the fly-ball type and is fastened on the generator shaft. As the speed is increased to a predetermined point, the weights are thrown out due to the centrifugal force and the contacts are made by "knife blades" being forced into the proper contacts.

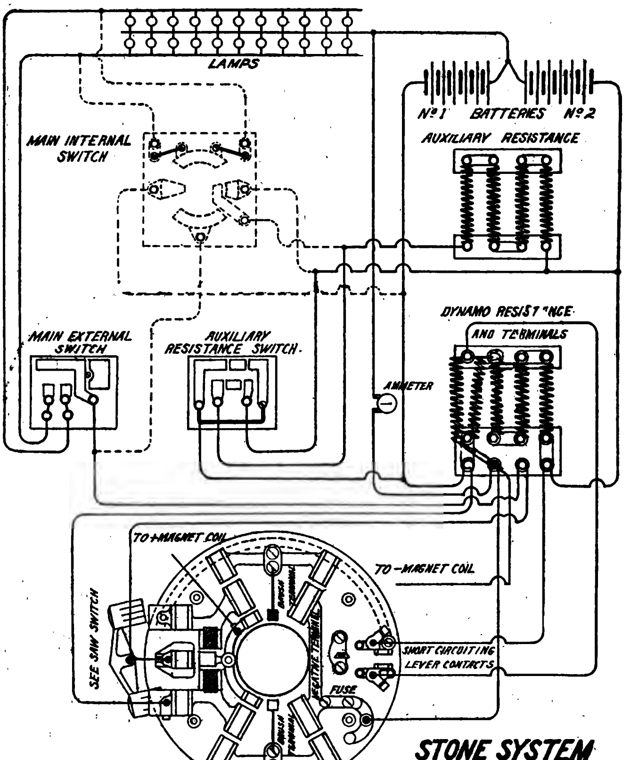


Fig. 42. Wiring Diagram

The car having attained the "cutting-in" speed the centrifugal force on the governor weights will throw the pole changer to the proper position, and cut in the automatic switch. The generator is then supplying the current, any excess above that required for the lights going to the batteries. If the speed increases above the point at which the automatic switch is thrown in, the belt, if properly adjusted, will begin to slip as the generator is loaded, thus causing the voltage to drop; consequently decreasing the current.

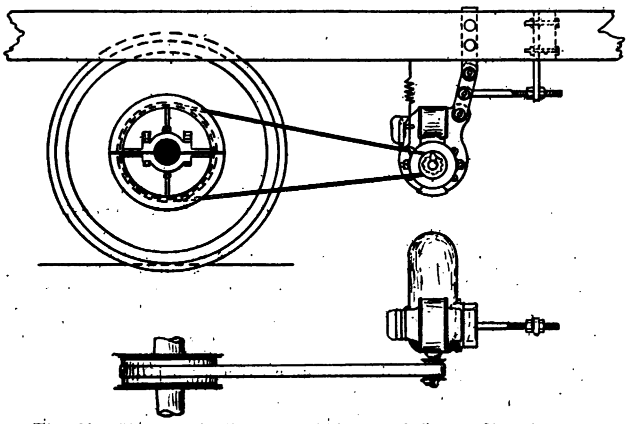


Fig. 41. Stone Axle Dynamo—Method of Suspending Dynamo

UNITED STATES LIGHT AND HEATING CO.

The generators are made in several sizes known as L, M, and O types. Each generator is provided with four supporting lugs or feet, made in the form of split bearings, which latter are provided with bushings which may be replaced when worn. These four bearings permit the generator to be placed upon and secured to the large "U"-shaped links of the suspension. The generators are made with solid bronze bearings or with ball bearings, the former being lubricated by ring chain oiler and the latter by grease forced into the bearing by a standard gun.

Pole Changer: The brush holders are mounted on a carrier which is carried on ball bearings, which enable it to rotate freely within the casing of the generator. The friction between the brushes and the commutator is sufficient to cause the brushes, and with them the carrier, to be dragged around as the commutator revolves. The angular motion of the carrier is arrested by means of a movable stop. When the armature revolves to a right-hand direction the brushes and carrier are rotated to the right and arrested by the stop in the correct position for commutation, and vice versa. As the rotation of the armature having been reversed, and also the position of the brushes, it is obvious that the actual polarity of the generator terminals is preserved.

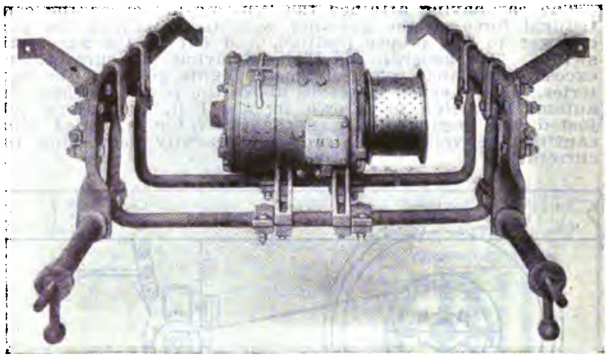


Fig. 43. Narrow Non-adjustable Parallel Link Suspension

Suspension: (For use on steel trucks and especially under cars having deep center sills, the suspension shown in Fig. 44 is applicable.) For use on wood trucks, some steel trucks, but especially with cars with deep center sills, the suspension shown in Fig. 43 is applicable. This has become known as the narrow style, because the side bars are relatively close together, forming a narrow frame. The "U"-shaped links upon which the generator is mounted are non-adjustable so far as their pivotal or vertical length is concerned. The side bars are usually fastened by means of bolts by means of wheel guards to a point in the transit.

Automatic Switch: The connection between the generator and the rest of the system is controlled by a generator

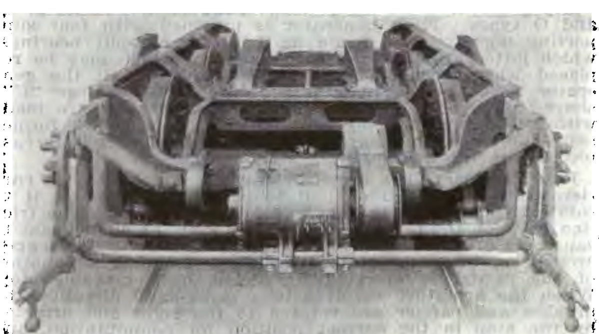


Fig. 44. Type M-3 Generator Mounted on Wide Non-Adjustable Parallel Link Suspension, Applied to Steel Truck

switch, consisting of a solenoid composed of two coils, one the lifting or closing coil and the other the releasing or opening coil. These coils act upon a plunger, which is drawn up by the lifting coil. When so drawn up, a metal brush attached to the plunger connects two terminals, thus connecting the generator to the battery. The solenoid switch closes the connection between the main feed wires when the generator has attained sufficient speed for normal voltage, and opens automatically when the generator drops below the operating speed.

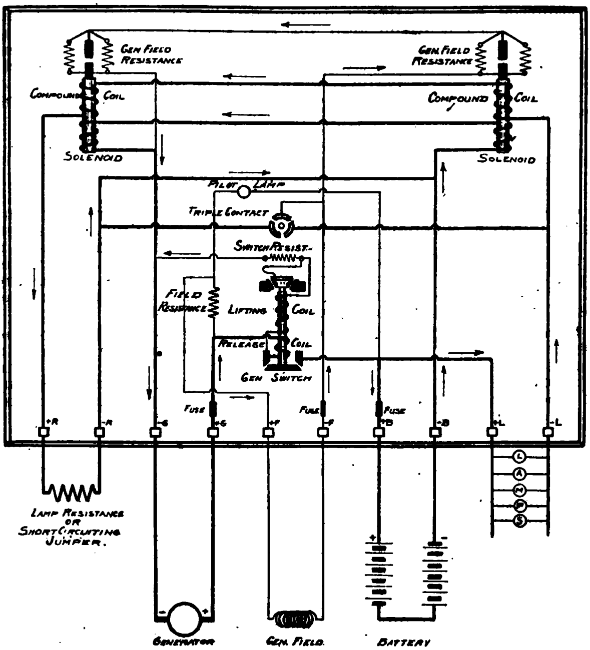


Fig. 45. Diagram of Bliss System Type F. Constant Current Regulation

U. S. L. TYPE "F" SYSTEM

Regulator: The regulator consists of two solenoids which are wound with heavy wire and connected in series with the main generator circuit. Soft iron plungers are used which are connected with a system of levers, and are free to move vertically. Each plunger has mounted on the upper end a carbon electrode which is normally in contact with a stationary carbon electrode. These electrodes normally short-circuit a fixed resistance connected in series with the generator field and these resistances are "unshorted" by sepa-

rating the carbon electrodes, and the machine is, so to speak, practically killed. The rheostat consists of two steps, one of which contains three times the resistance of the other. Both resistances are cut out normally by the carbon electrodes which are forced together by the action of retractile springs.

Operation: The tension of the springs is so adjusted that when a predetermined current flows through the solenoids, the plungers are pulled down, just breaking the short circuit which has normally kept the resistance out of the field circuit. When the short circuit is broken, the field current is immediately reduced, and the generator voltage drops, decreasing the pull on the solenoid plungers. The retractile springs cause the carbons to short circuit the field resistance, the generator voltage rises, and the cycle of operation is repeated, the result being that the main current oscillates or pulsates with high frequency between two narrow limits.

A wiring diagram of this system is shown in Fig. 45.

U. S. L. TYPE "C" SYSTEM

Generator Regulator: The generator regulation is maintained by a solenoid having a shunt winding connected directly across the generator circuit, which actuates a lever exerting a pressure on a carbon pile disk resistance. As the speed of the machine increases the pressure on the disks is decreased, thereby inserting a resistance in the field circuit and reducing the generator voltage.

Lamp Regulator: The lamp regulator is similar to the generator regulator, the carbon pile resistance being in series with the lamp circuit. In order, however, to obtain a more delicate adjustment a reed vibrator is used to cut in and out a resistance across the carbon pile, thus maintaining the lamp voltage practically constant.

U. S. L. TYPE "P" SYSTEM

Generator: This generator is of the multipolar type with a cast steel field frame. The armature is form wound. The bearings are of the ring oiling type. There are two brush holders which are accessible through a hand-hole with removable cover.

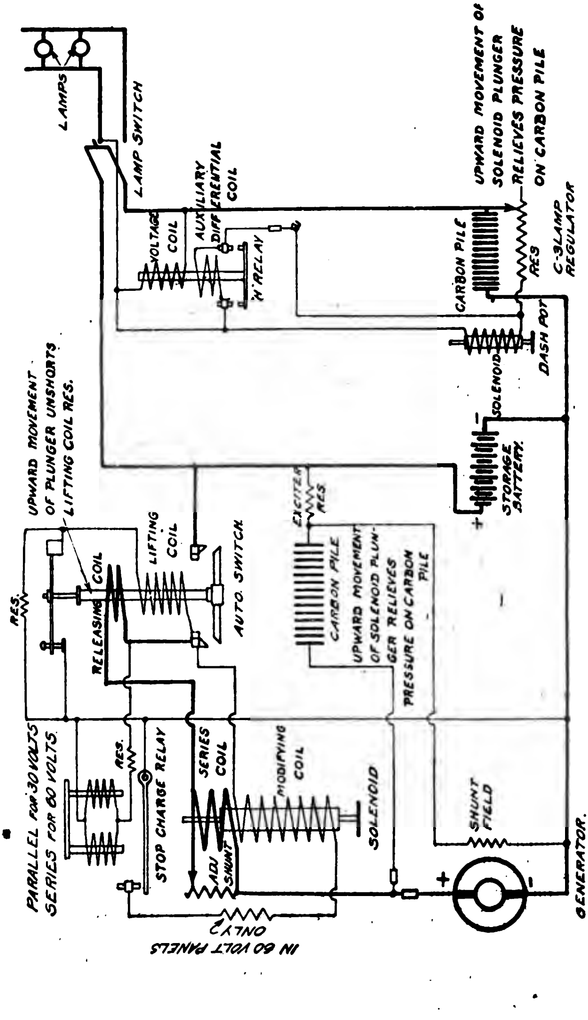
Pole Changer: The pole changer consists of a movable wrought iron ring carrying its current contacts, stationary contacts and steel plunger which is attached to the armature shaft. The function of the plunger is to engage the movable ring under a train speed of three (3) miles per hour, and rotate it so as to maintain the generator in proper relation with the battery. Above a speed of three miles per hour the plunger is disengaged by centrifugal force.

Drive: The generator is belt driven, the proper tension being maintained by the use of helical springs attached to the under side of the generator and made adjustable with the suspension.

Suspension: An overhung suspension is employed. The generator is supported from a 2-5/16" shaft which passes through two lugs, the latter being integral parts of the generator frame. Alignment of the machine may be made by shifting the bearings carrying the above mentioned shaft. The weight of the generator is taken directly by spring

bars, bolted to the truck. Cushion and recoil springs are inserted between these spring bars, and a rigid "angle" which is also bolted to the truck.

Regulation: The regulator consists of an automatic switch, a carbon disc pile, actuated by a series solenoid, and



SCHEMATIC DIAGRAM OF C-7 PANEL

Fig. 46

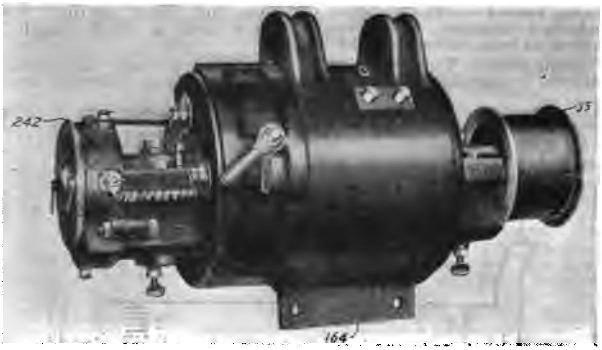


Fig. 47. U. S. L. Type "P" Generator

a dash pot. The carbon pile is connected in shunt with a resistance and the combination connected in series with the generator field which is protected against sudden severe fluctuations of pressure by a dash pot filled with glycerine. The generator is made to "pick up" by exciting the field from the battery through a resistance.

Lamp Regulation: The lamp regulation is accomplished by means of a fixed resistance in the lamp circuit.

Operation: Assuming the car to be standing still, the fields of the generator will be excited through a high resistance (to insure picking up). When the car has reached an approximate speed of five (5) miles per hour the pole changer has produced the proper relation between generator and battery voltage. Up to the time of the closing of the automatic switch, which makes the generator voltage slightly in excess of the battery voltage, the carbon pile shunted across the generator fields has been inactive. The sudden flow of the battery and lamp current energizes the solenoid connected with the carbon pile; the latter is compressed, shunting the current around the field, thus reducing the generator output to a predetermined value.

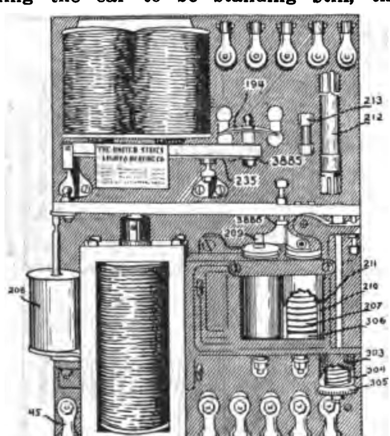


Fig. 48. U. S. L. Type "P" Panel

U. S. L. TYPE S-1

The Type S-1 Panel consists of: 1. The generator current regulator. 2. The generator potential regulator. 3. The standard automatic switch. 4. The lamp regulator relay. In addition, it has mounted upon it the generator armature fuse and the generator field fuse. The lamp regulator, which is an independent piece of apparatus controlled by the lamp regulator relay (4), may be mounted, preferably inside the car, or underneath the floor of same, as the owner may elect.

The distinguishing features of the S-1 panel are the generator, current regulator and the generator potential regulator.

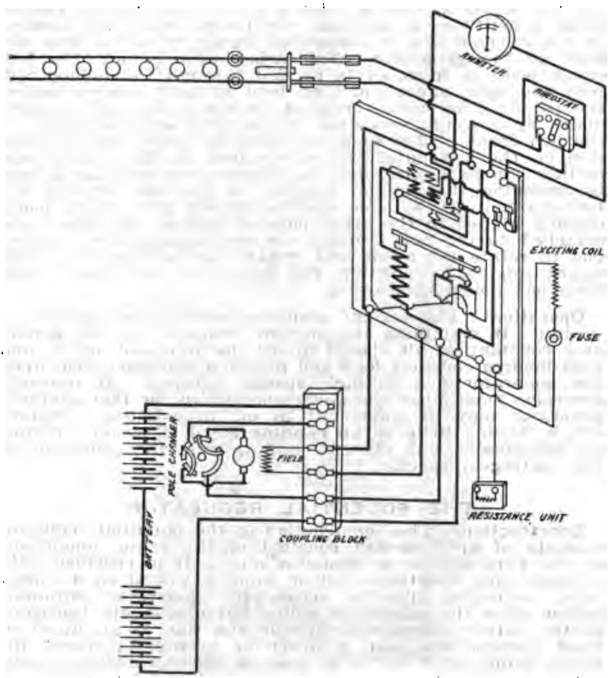


Fig. 50. U. S. L. 13 Type "P" System

GENERATOR CURRENT REGULATOR

Construction: The current regulator consists of an iron-clad solenoid having a single heavy winding of edgewise wound copper bar directly in series with the armature of the generator, and through which the total armature current of the generator flows. The plunger of this solenoid

is free to move in a vertical direction through a distance of about ⅜ inch. To the lower end of the plunger is attached a graphite piston, which fits a cylinder or dash pot which, in turn, forms a part of and is cast integrally with the frame of the solenoid. This dash pot is nearly air-tight and contains no liquid of any kind, the entrapped air and the small clearance between the piston and the walls of the cylinder affording all the damping action necessary to prevent sudden or jerky movements of the plunger. The upper end of the plunger engages a roller, which is attached to the forked end of the horizontal arm of a bell crank lever mounted upon a hub post attached to the panel. The end of the vertical arm of said lever is attached to a thrust plate and carbon terminal block, which latter engages one end of a horizontal pile of carbon disks. The other end of the pile abuts against a solid support. The pile of carbon disks constitutes a variable resistance under the control of the solenoid and is connected dirctly in series with the field of the generator. The arbor upon which the bell crank lever is mounted is carried through the hollow hub post and slate panel and then bent at right angles, behind the panel. The initial pressure on the carbon pile is produced by a weight mounted on the rear horizontal arm of the bell crank. This weight is fixed in value, and its location on the horizontal arm determined in the factory and neither can be altered, but its effectiveness may be altered by changing the angular position of the rear arm of the bell crank lever, by means of a knurled nut which, being directly pinned to the arbor passing through the panel and attached to the bell crank by a removable screw, enables one to rotate the arbor and engage the bell crank at different angles by shifting the screw in the knurled nut from one hole to the other.

Operation: The current regulator serves two purposes: First. It maintains the current delivered by the generator constant at all speeds above the full load speed, and thus insures constant load and prevents excessive load upon the generator due to high speeds. Second. It prevents excessive loads upon the generator due to the fact that the generator may at times cut in on an exhausted battery which, having little or no counter E. M. F., would permit an abnormally high current to flow from the generator at the cutting-in speed.

THE POTENTIAL REGULATOR

Construction: The construction of the potential regulator consists of an iron-clad solenoid of the same dimensions as the Type K-1 lamp regulator relay. It is provided with a single high resistance coil or winding wound on a copper tube, connected directly across the generator terminals which, after the automatic switch has closed, are the same as the battery terminals. Within the tube is an upper or fixed plunger and also a lower or movable plunger, the latter being mounted on a pair of parallel motion reeds, which permit of a frictionless vertical movement of said plunger within the tube. An air dash pot is formed integrally with the lower portion of the solenoid frame and a small graphite piston fitted therein, which is connected to the lower end of the movable plunger by means of a self-aligning connection. The dash pot serves to prevent sudden or jerky movements of the movable plunger. The bottom of the dash pot is made of molded insulating material, threaded and fitted into the dash pot. This insulating cover is provided with a carbon block terminal

mounted on a screw, which is threaded through the cover and provided with a lock nut. The frame of the solenoid forms one terminal and the insulated carbon contact attached to the cover forms the other terminal of the resistance which is included in the field circuit of the generator and normally short-circuited by the contact between the graphite piston and the lower carbon terminal. A brass tail rod is attached to the movable plunger and passes upward through a clearance hole in the stationary plunger and carries on its upper end a cross bar, one end of which forms a rigid finger for the attachment of the helical adjusting spring, while the other is formed into a tappet, which engages a roller on the end of a small multiplying lever. This lever is fulcrumed on a rigid support attached to the upper part

Fig. 49. Type S-1 Generator Regulator Panel with Type B-1 Lamp Regulator Panel Mounted Underneath

of the solenoid frame. The lever engages a short vertical stud which passes up through the support, to which the lever is attached, and supports the lower contact plate on which rests a vertical pile of carbon discs. The discs are confined within a cage whose vertical rungs are attached to the above mentioned support. The rungs are insulated with lava tubes and thus the carbon pile is insulated from all metal parts with the exception of its lower carbon plate. A bonnet is attached to, and insulated from, the solenoid frame and covers and conceals the carbon pile and its operating mechanism. In the top of the bonnet is mounted, by means of a steel adjusting screw provided with a lock nut, a carbon contact block which may engage the upper end of the carbon pile. A pressed cap fits over the top of the bonnet and covers and conceals the upper part of the carbon pile and the upper carbon contact.

The action of the small lever provided with a roller is simply to increase the pressure exerted by the movable plunger of the solenoid upon the carbon pile, the dimensions of the lever being such that a multiplying effect of 2 to 1 is secured. The adjusting spring above mentioned is attached, as was stated, to one end of the cross bar fastened to the brass tail rod and is enclosed within a brass tube mounted in lugs which are cast integrally with the frame of the solenoid. The magnetic pull of the coil is opposed by the weight of the carbon pile, the multiplying lever, and the movable plunger, and also by the tension of the adjusting spring.

Operation: The carbon pile is connected as shunt to the field winding of the generator, but the contact between the top of the carbon pile and the upper contact block is normally broken or open. The tension on the adjusting spring is so regulated that the movable plunger remains in its lower position until a voltage of 42 is impressed upon the coil of the regulator. This voltage is sufficient to cause the plunger to move upward, thus breaking the connection between the graphite piston of the dash pot and the lower carbon contact block, which motion throws into series with the field of the generator the fixed resistance mentioned above. The movable plunger moves instantly to its upper position and raises the carbon pile up into contact with the upper contact block, thus establishing a variable shunt around the field winding of the generator. The regulator now operates to maintain the voltage of the generator at 35 volts, by varying the resistance of the shunt across the field winding. An increase in voltage above 35 decreases the resistance of the carbon pile and deflects or shunts current from the generator field winding, thus tending to lower its voltage. A similar, though opposite action takes place with a decrease of generator voltage.

Three adjustments of the potential regulator are necessary, but when once made no further adjustments should be necessary for long periods.

First. The lower carbon contact must be adjusted until a definite contact is secured.

Second. The tension spring must be adjusted until 42 volts just raises the movable plunger.

Third. The upper carbon contact must be adjusted until the generator voltage is held to 35 volts.

The potential regulator performs primarily two functions:

First. It responds to and prevents a rise of voltage beyond that value which is assumed to represent a condi-

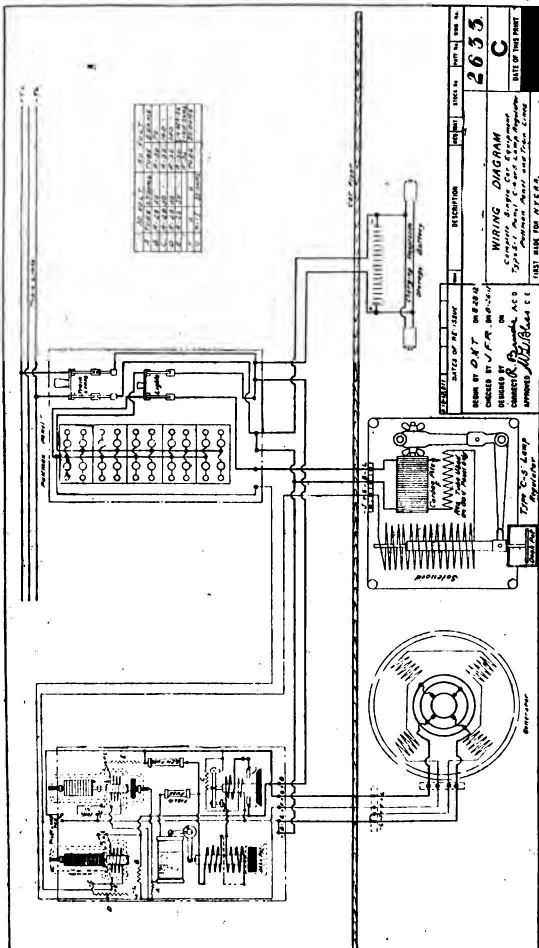


Fig. 51

U. S. L. Type S-1 Panel C-4 or 5 Lamp Regulator

tion of full charge in the battery. In the 30-volt system this is assumed to be 42 volts, and is undoubtedly very nearly correct. A voltage of 42 may be produced in a number of ways, some normal and others abnormal.

The normal manner of obtaining 42 volts in the system is by allowing or causing the battery to charge at some reasonable rate or near the normal charging rate until the battery voltage gradually rises to 42 volts. This action may be fairly continuous or decidedly intermittent, depending upon the train schedule.

On the other hand, a voltage of 42 will appear abnormally and without representing full charge in the batteries when, for any reason, the resistance of the battery circuit becomes abnormally high. This may occur either through sulphatation, loss of electrolyte or the battery circuit actually opening.

As an abnormal rise of voltage is more or less proportional to the resistance introduced into the battery circuit, it is seen that the most violent upward rush of voltage must occur when the battery circuit is opened, for under these conditions the resistance approaches infinity and it requires an infinite voltage to force a finite current through an infinite resistance. The tendency of the voltage to rise with the increase of battery resistance is due to the characteristics of the current regulator, the tendency of which is really, as was previously explained, to maintain its ampere-turns constant, or, what is the same thing, its current constant. In trying to maintain constant current through an abnormally high battery resistance, the current regulator requires and permits an abnormally high voltage to develop. This is no reflection, however, upon the current regulator, as it is the fundamental property of such a regulator. Actual opening of the battery circuit is not likely to occur with modern batteries and wiring, but it is a favorite condition introduced into most specifications as a test of the ultimate ability of the potential regulator to prevent damage and to maintain, if possible, an operating system without a battery.

The first function of the potential regulator is essentially protective, preventing an increase in voltage above 42. It is assumed that when 42 volts appears, it has been developed under normal conditions, viz., due to charging the battery. At 42 volts, the potential regulator responds, and throws into the field circuit of the generator a fixed preventive resistance, but one not having a value sufficiently high to appreciably weaken the field. At the same instant, a small carbon pile under the control of the same solenoid of the potential regulator is bridged across the shunt field of the generator. The function of this resistance is to prevent the carbon pile from short-circuiting the generator, as obviously a shunt upon a shunt winding would. The tension spring of the potential regulator is so adjusted that as soon as the same has come into play, the tendency is to regulate the generator as a strictly constant potential machine at exactly 35 volts, which is the floating voltage of 16 cells of Plantê battery. The result is that no matter what the speed of the generator may be at the time the potential regulator acts, the voltage of the same is instantly brought to 35 volts, at which value it remains over all speeds above the cutting-in speed and thereby maintains the battery current at zero. There is an abrupt reduction of the battery current to zero and no lower, the generator voltage simply falling to 35, where it is held as long as the

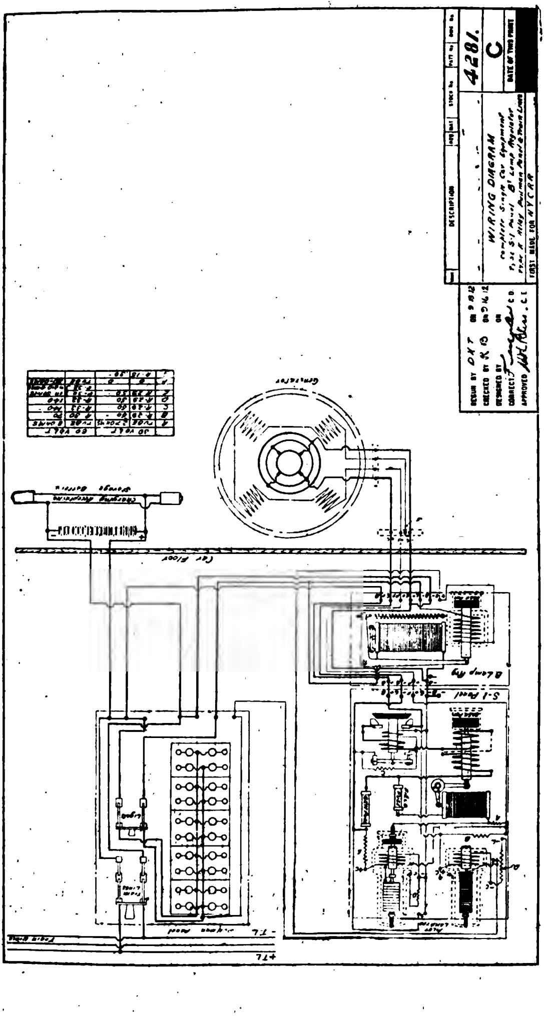


Fig. 51 U. S. L. Type S-1 Panel B-1 Lamp Regulator

generator runs above cutting-in speed. Any lamp load thrown on or existing at this time will be carried by the generator, as the voltage of the latter is held constant, notwithstanding the tendency of such a lamp load to lower the system voltage. If, however, an abnormal lamp load heavy enough to reduce the voltage of the system to 33 volts, in spite of the efforts of the potential regulator to maintain 35 volts but still not as great as the full load capacity of the generator, is thrown on, the battery would naturally be caused to discharge and the generator would carry only a portion of such lamp load. But such a reduction in voltage would restore the plunger of the potential regulator to its initial position, which would short-circuit the fixed resistance and remove the carbon pile shunt from the field winding of the generator, and instantly the current regulator would come into play and permit the generator to put out its full load current, which now being divided between the battery and the lamps, the lamps presumably receiving the greater portion, the charging of the batteries at a low rate would begin again and the battery voltage would ultimately work up to 42, depending upon how much discharge had taken place previous to the restoration of the potential regulator.

THE TYPE K-1 LAMP RELAY

The Type K-1 lamp relay is of more recent design and construction. It consists of an ironclad solenoid, whose frame is of exactly the same dimensions as that of the potential regulator and whose single high resistance coil is connected across the lamp mains. Thus the coil measures and is responsive to variations in lamp voltage. The coil is wound up on a copper tube and inside the tube is an upper or stationary plunger, reaching about half way down the tube and a lower or movable plunger, supported on a pair of parallel motion reeds which permit of a frictionless vertical movement of the lower or movable plunger within the tube. Attached to the movable plunger is a brass tail rod, which extends and carries upon its upper end a cage containing a vertical pile of small carbon disks. The carbons are insulated from the rungs of the cage by lava tubes but are connected with the metallic bottom of same. A rigid finger extends forward in a horizontal direction from the bottom of the cage, and to its end is attached a helical spring enclosed within a vertical brass tube mounted in lugs, which are cast upon the solenoid frame. The magnetic pull of the coil is opposed by the weight of the movable plunger tail rod and cage, and also by the tension of the adjusting spring. Mounted upon but insulated from the solenoid frame is a bonnet which covers and conceals the cage, carbon pile and tension spring, and which carries at its top a fixed contact consisting of a small carbon block mounted upon the end of a steel screw, which is threaded into the open top of the bonnet and provided with a lock nut. Over the top of the bonnet is fitted a pressed cap, which covers and conceals the carbon block and its mounting screw. The carbon block is adjusted in the factory to make proper contact with the top of the carbon pile. The normal pressure on the pile is secured by adjusting the tension spring in connection with the carbon block, and this pressure is made such that when normal voltage is applied to the coil, the resistance of the carbon pile is just sufficient to allow the correct current to pass through the carbon pile and the operating solenoid of the lamp regulator which, in turn, is so adjusted that the

correct pressure is exerted on the carbon pile of the lamp regulator, and thereby the correct resistance is inserted in the lamp circuit, producing normal voltage on the lamps. A slight rise in lamp voltage causes an increased pressure on the carbon pile of the relay and a multiplied increase of current in the lamp regulator solenoid which, causing a decreased pressure on the carbon pile of the lamp regulator, increases the resistance in the lamp circuit and restores the lamp voltage to normal or very nearly normal. As an actual matter of fact, the lamp voltage does not increase and then decrease as the above description would naturally lead one to suppose. Undoubtedly the chain of reasoning is logical, but it is the tendency of the lamp voltage to rise that is checked in its incipiency. Conversely, and by the same process of reasoning, it can readily be understood how a tendency toward reduced lamp voltage is checked.

TYPE B-1 LAMP REGULATOR

Construction: The Type B-1 lamp regulator consists of an iron-clad solenoid of the same dimensions and size as the frames of the solenoids used in the automatic switch and the generator current regulator. This solenoid is provided with a single coil of a high resistance, connected in series with the carbon pile of the Type K-1 lamp relay. The action of the relay upon the lamp regulator has already been described. The solenoid frame is mounted upon a slate, similar in character to the slate forming the base of the Type S-1 panel. Mounted upon the slate is a single cast bracket which forms a support for the operating lever and for the rods which hold the large carbon pile in position. The main operating lever is of bell crank form, the long end being attached to a movable plunger in the solenoid. The lower end of the plunger in the solenoid is attached to a graphite piston which works in a dash pot cast integrally with the frame of the solenoid. The piston fits the dash pot almost air tight and affords all the damping action necessary. The multiplying lever is a short bar pivoted on the same casting which supports the main lever and provided with a small roller at its upper end which engages a tappet formed upon the vertical portion of the bell crank lever.

The Type B-1 lamp regulator is mounted upon a slate of the same width as the Type S-1 panel and is provided with similar feet and frame for ready mounting. When mounted directly under the S-1 panel, all the wiring is carried from the panel to the regulator by copper strips, which obviate the necessity of wiring more than one piece of apparatus.

The Type B-1 lamp regulator may be made for mounting underneath the car body, if so specified.

SECTION IV

COST OF EQUIPPING AND OPERATING ELECTRICALLY LIGHTED CARS

INCLUDING TABLES OF COST OF EQUIPPING AND MAINTAINING ELECTRICALLY LIGHTED CARS WITH DIFFERENT SYSTEMS

COST OF EQUIPPING AND OPERATING ELECTRICALLY LIGHTED CARS

While direct comparison of costs of electric car lighting with different systems is possible, such comparison would be valueless without an exact description of apparatus, methods of keeping records and items included. A comparison, for example, of the costs of lighting, by a straight storage system with a head end or axle generator system would be inaccurate and useless without definite knowledge of all the items upon which it is based. Moreover, a comparison between the costs for the same type of systems on different roads would be of no use when the same items are not considered or radically different methods of cost keeping are in vogue.

The following are the variables which directly affect the cost of train lighting:

System:

Straight Storage—Make, capacity and number of batteries. Yard and repair facilities. Labor cost.

Head End—Make, capacity and number of batteries per train. Make and capacity of generator. Yard and repair facilities. Labor cost. Method of operating, viz. Time operative. Reliability of service.

Axle Generator—Make, capacity and number of batteries. Make, capacity and generator. Yard and repair facilities. Labor cost.

There apparently is a tendency by some roads to charge certain Train Lighting Repair Costs against car or shop repair, thereby reducing the electric lighting costs at the expense of other accounts. It can be readily seen that where such practice is in vogue a true cost of electric lighting cannot be obtained, and it would be unfair to attempt to compare such records against those of other railroads where accurate accounts are kept. Neither is it fair to compare the cost of operation and maintenance of cars which are very poorly lighted or where lighting reliability is a second consideration against the costs on those roads which insist upon properly lighted cars and absolute continuity of the lighting service at all times.

The following pages show the cost of operation and maintenance of electrically lighted cars and are taken from averages of several different roads that endeavor to properly illuminate their cars, insist upon continuity of service, and it is believed have first class cost keeping systems.

AVERAGE COST PER CAR FOR EQUIPPING EIGHTEEN 60-FOOT WOOD COACHES WITH ELECTRIC LIGHTS

Straight Storage System with Pullman Head-end Wiring

Batteries, 32 cells, 280 ampere-hours capacity, in lead-lined tanks	$ 600.00
Fixtures, 5 four-light clusters or single 50-watt "Mazda" fixtures	125.00
Receptacles, 8	2.80
Wire	39.14
Conduit	19.80
Distributing Panel	5.45
Junction Boxes	5.85
Lumber (Battery Boxes)	10.79
Paint, etc.	2.52
Labor	78.99
Freight	6.60
Miscellaneous, Including Gibbs No. 3 Train Line Connectors	86.16
	$ 983.10

AVERAGE COST PER CAR FOR EQUIPPING TWELVE 10-TABLE DINING CARS WITH ELECTRIC LIGHTS

Axle Generating System

Batteries, 16 cells, 280 ampere-hours capacity, double compartment, lead-lined tanks	$ 300.00
Fixtures, 7 four-light clusters, or single 50-watt "Mazda" fixtures	175.00
Receptacles, 14	4.55
Wire (No Train Line Wires)	26.18
Conduit	18.60
Distributing Panel	6.50
Junction Boxes	10.20
Lumber (Battery Box)	10.90
Panel	2.95
Generator	550.00
Labor	98.65
Freight	12.15
Miscellaneous Material	94.30
	$1,309.98

COST OF OPERATING 32-VOLT AXLE GENERATOR SYSTEM

Average cost per car per month for maintaining 950 electrically lighted sleepers operating 11,000 miles per month. Averaged from one year's record.

Labor and Supervision	$ 9.12
Current	.71
Battery Renewals	3.73
Separator	.36
Acid	.31
Tanks	.47
Lamps	2.11
Axle Generator	2.46
Miscellaneous Material	1.90
General Charge	.28
	$21.45

No interest or depreciation included in the above.
No charge for power en route.
Equipment four years old (averaged).

Note: No record of operating costs for head-end systems are given as the figures vary considerably with different methods and systems, as for instance, it would be an unfair comparison to attempt to compare a system using one set of batteries per train with the same system using batteries on each car.

COST OF OPERATING 63-VOLT STRAIGHT STORAGE SYSTEM

Average cost per car per month for maintaining twenty 12-section sleeping cars for twelve months having twelve hour all-night runs:

Labor	$ 5.93
Current	11.16
Battery	5.81
Acid	.47
Lead Linings	.11
Separators	.16
Tanks	.58
Lamps	2.19
General Charge	.66
Total	$27.07

Interest on Car Equipment should include all apparatus on car used in connection with producing light, say at 5%.

Depreciation on Car Equipment could be divided as follows:

Conduit	5%
Fixtures	5%
Wiring	5%
Batteries	
Battery Boxes	10%
Generator	10%
Generator Regulator	10%
Lamp Regulator	10%

Note: The battery depreciation will vary with the various types of batteries and methods of operation, but a fair average figure is believed to be about 15%.

When possible this figure should be disregarded and a figure as obtained by maintenance in actual service extending over a sufficient number of years to obtain a true average value should be used.

Maintenance should include the following items:
- Conduit.
- Wiring.
- Batteries (see note under depreciation).
- Battery Boxes.
- Generator.
- Generator Regulator.
- Lamp Regulators.
- Lamps.
- Fuses.

Labor:
- General Supervision.
- Yard Supervision.
- Accounting.
- Yard Labor.
- Train Labor.

Traveling Expenses.

Power en route, and at Terminals.

Transportation Expenses: Moving apparatus over road at........per ton mile.

Terminal Facilities:
- Interest on Yard Wiring Investment.
- Depreciation of Yard Wiring Investment.
- Maintenance on Yard Wiring.

______________________________ Railroad

STATEMENT SHOWING PERFORMANCE AND COST OF MAINTAINING ELECTRIC LIGHTING EQUIPMENT PER CAR EQUIPPED PER MONTH

DURING MONTH OF ______________ 19__

BY ______ VOLT ______________ METHOD OF LIGHTING.

CLASS OF CARS

	COACHES		SLEEPERS		DINERS		MAIL CARS	
	Material	Labor	Material	Labor	Material	Labor	Material	Labor
INTEREST Rate% ( )								
DEPRECIATION Rate% ( )								
TAXES Rate % ( )								
INSURANCE Rate% ( )								
HAULAGE Rate ( )								
POWER Rate ( )								
*SUPERVISION								
BATTERIES								
GENERATING UNITS								
DRIVE (Belts, fasteners and chains)								
PULLEYS AND SPROCKETS								
REGULATORS								
LAMPS								
CHARGING CURRENT								
SWITCHBOARDS								
WIRING								
WIRE REPAIRS								
SHOP ORDER REPAIRS								
TOTAL								
CREDIT SCRAP MATERIAL								
NET TOTAL								
NET TOTAL COST PER CAR								
NET TOTAL COST PER CAR‡								
NUMBER OF CARS EQUIPPED								
TOTAL MILEAGE								
AVERAGE MILES PER CAR								
AVERAGE COST PER 1000 CAR MILES								
AVERAGE COST PER 1000 CAR MILES‡								
TOTAL NO. OF FAILURES								
FAILURES PER CAR MONTH								
AVERAGE MILES PER FAILURE								
AVERAGE MILES PER FAILURE‡								
AVERAGE AGE OF EQUIPMENT								
AVERAGE COST OF BATTERY								
AVERAGE COST OF GENERATING EQUIPMENT ACCESSORIES AND REGULATORS								
‡SAME MONTH YEAR PREVIOUS								

VOLTAGE FALLING BELOW 1.8 VOLTS PER CELL WITH LIGHTS ON CONSTITUTES A FAILURE.

STANDARD FORM FOR CAR LIGHTING COST ACCOUNTING

Note: Cost of power at terminal should include all interest, depreciation and maintenance on power plants through power plant switchboard.

General Expense, such as charging cables, tools, boots, etc.

The preceding page shows a proposed standard form for car lighting cost and accounting that has been recommended by the Railway Electrical Engineers' Association Committee on Accounts and Reports for the year 1911. It will be noted that the proposed form covers all materials and information likely to be used or required in Electrical Train Lighting.

The Committee recommends a 5% annual interest rate for the entire electrical investment per car and 5% per annum for depreciation or rather obsolescence, as it is believed that while the apparatus may not be completely worn out at the end of 20 years' service, nevertheless, it would undoubtedly be replaced by later type apparatus.

The proposed form is very complete and unquestionably would be of much value to operating engineers to check their costs against those of other roads, nevertheless, it is a question if the officials having the deciding of such matter would agree to some one form of reports.

SECTION V

STORAGE BATTERIES

INCLUDING CONSTRUCTION, TYPES, THEORY, CAPACITY, CHARGE AND DISCHARGE CURVES, TROUBLES AND REMEDIES, PUTTING INTO COMMISSION, OPERATION

STORAGE BATTERIES

The accumulator or storage battery most generally used for Electric Train Lighting purposes in the United States has been of the Lead, Lead Planté or "formed" type, although the Faure or "pasted" type and the nickel steel battery as manufactured by the Edison Storage Battery Company have received no little attention from the Railway Companies during the past two or three years. While many claims of superiority are made by the advocates of each type of battery, it is not within the province of this book to attempt in any way to discuss their relative merits.

The following information pertaining to various types of batteries, their care and operation may be of value to those readers who are interested in this particular apparatus.

Plante-Batteries:

Positive plates, one or more.

Negative plates, one more than the number of positive plates.

A solution in which the plates are submerged, known as electrolyte.

Separators for preventing the positive and negative plates from coming in contact with each other.

A containing vessel.

Connectors for joining electrically the positive and negative plates of adjoining cells.

Positive: The positive plate may be either of the Planté or "formed" type, or the Faure or "pasted" type. The Planté or "formed" type of positive plate consists essentially of a sheet of lead, the surface of which, by chemical or electro-chemical means has been converted into lead peroxide (PbO_2), which is of a rich chocolate brown color. The body of the lead sheet serves as a support for the lead peroxide or "active material," as a conductor for the current and as reserve material to be converted into lead peroxide as the original "active material" is lost by reason of becoming loose from lead sheet and falling to the bottom of the containing vessel.

Negative: The negative, like the positive, may be either of the Planté or Faure type.

Similarly the surface of the negative plate is converted into "active material," but in this case it is spongy lead (Pb) or lead which is very porous. This spongy lead is of a slate gray color.

Electrolyte: The electrolyte consists of dilute sulphuric acid (H_2SO_4) of a normal specific gravity ranging from 1.220 to 1.250 when the battery is fully charged.

Separators: The separators must prevent the positive and negative plates from coming into contact, but they must not prevent the electrolyte from reaching the plates, must not be affected by the electrolyte, and must not contain any substance injurious to the battery. Hard rubber is generally used for this purpose. It is made up in the form of a thin sheet having numerous small perforations, and with several vertical ribs extending the length of the sheet to give the proper separation between the adjacent positive and negative plates.

Containing Vessel: The containing vessel is generally a double compartment wooden tank, lead lined, resting on four porcelain rollers and provided with porcelain buffer blocks at the ends and sides. These porcelain rollers and buffer blocks are for the purpose of insulating the tanks

and preventing "grounds" which would result in electrolytic action and thus destroy the lead linings. The rollers also serve to make the tanks easier to handle. Fig. 2 shows the same general arrangement of tank but with hard rubber jar in place of the lead lining.

Fig. 1. Standard Types of Double Tanks and Elements
Hardwood tank coated with acid proof paint. Lead lining, set in petrolyte or similar compound and paraffine.

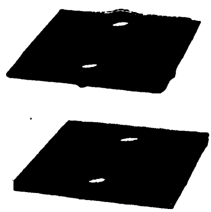
As will be seen in Fig. 2 each compartment contains a positive and negative group of plates, the several plates being burned to their respective cross-straps or bridges with a terminal post projecting through a soft rubber bushing set in hard rubber cover.

The groups of plates are supported on porcelain bottom rests, which provide space for the "active material" which

sloughs off and which would otherwise "short-circuit" the plates, thereby causing the battery to become inoperative or "dead".

When lead-lined tanks are used, thin sheets of hard rubber are slipped between the plates and the walls of the lead lining at both sides and ends to prevent short-circuiting of plates. The top edges of the lead lining are burned to a frame, cast from an alloy of lead and antimony, and recessed. A hard rubber cover lies in this, leaving an open space around all four sides. This space is then filled with

Lead Lining Crowned



Hard Rubber Covers Sealed Type Soft Edge Type

Hard-Rubber Jar

Perforated Hard-Rubber Separator

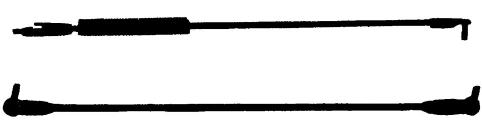
Element on Bottom Rests

Insulating Sheet Hard-Rubber

Negative Terminal Bushing

Positive Terminal Bushing

Hard-Rubber Vent



Cable Connections

Fig. 2

a sealing compound to stop leakage of the electrolyte, for, if this is not prevented, the tanks become acid soaked and "grounded" with results as mentioned above. In addition, the acid attacks and corrodes all adjacent metal work.

However, as gases are evolved during the process of charging, which must be allowed to escape, a plug which has a small vent hole is provided in the center of the cover. By removing this plug the electrolyte may be inspected and the height and specific gravity corrected.

Connectors: The terminals of adjacent cells are connected together, positive to negative, by means of No. 6 rubber-covered single braid wire. The ends of this wire are soldered into special copper or brass terminal lugs, which in turn are soldered into the terminal posts of the battery, a special low-melting solder being used for this purpose.

Manufacture: The capacity of a battery is dependent upon the amount of "active material" exposed to the action of the electrolyte. It is advisable to make the "active material" in a thin layer and obtain volume by increasing the area exposed. There are several reasons for this, but the principal one is that, were the "active material" of any considerable thickness, that is, ⅛-inch or more, the gas which is evolved during charge would dislodge the "active material," causing it to fall to the bottom of the cell. Also, the thicker the layer of "active material" the smaller the amount exposed to the action of the electrolyte, which action cannot penetrate to any considerable depth. For these reasons, manufacturers resort to various means in order to increase the superficial area, or area in contact with the electrolyte, as, for example, by casting the plate so that it is of cellular construction, or by corrugating the surface with tools, by rolling, spinning, plowing or swedging processes.

However, while increasing the exposed surface of the

Fig. 3. Gould Plate

Fig. 4. Willard Plate

"active material" is beneficial in one way, it is detrimental in another, as the life of a battery is dependent upon the amount of reserve lead that is available to be converted into "active material". Now, assuming several plates have the same weight of lead, it is obvious that the plate having the greatest area will also have the least reserve lead. The design of the battery plate as manufactured is therefore a compromise between these conflicting conditions.

Gould Plate: This plate, shown in Fig. 3, is formed by stamping the blank plate from rolled lead and then placing in a steel frame which reciprocates between two rapidly revolving mandrels on which steel discs and spacing washers are placed. The width and shape of grooves are varied by varying the gauge and form of spinning disks, while the length of the section spun is determined by adjusting the travel of the frame.

Willard Battery: This plate, shown in Fig. 4, is stamped from rolled lead, then placed in a machine similar to a "shaper," while the tool is passed over the plate turning up the ribs much in the same manner as a plow; hence it is known as the plowing process.

Electric Storage Battery: The positive plate is of the Tudor cast type consisting of a single integral piece of lead having a number of fine vertical ribs, with spaces between, which extend from one face of the plate to the other. The vertical ribs are tied together at short intervals by horizontal ribs, the whole being surrounded by a frame, integral with the plate.

Fig. 5. Tudor Positive Plate, Type E P Rolled Negative Plate Type E P—Electric Storage Battery Co.

The negative plate is stamped from rolled lead and the ribs are formed by placing the plate in a frame and reciprocating back and forward while pressing thin circular disks into the lead. These plates are shown in Fig. 5.

The Manchester positive plate, as made by the Electric Storage Battery Company, and shown in Fig. 6, is made by rolling lead ribbon into spirals and inserting the resulting buttons into circular holes which are cast in the antimony-

lead plate. When the plate is formed the expansion of the active buttons causes them to firmly wedge themselves in the hole.

Manchester Positive Group Box Negative Group
Fig. 6. Electric Storage Battery Co.

The Shelf negative plate consists of an unoxidizable alloy grid with vertical ribs and finely divided cross-ribs, or shelves, for holding the active material, which is locked into place by the tapered form of the shelves and ribs.

Fig. 7. National

National: This plate is of the rolled lead type, and ribs are formed by the reciprocating rocking action of a series of segmental knives or cutters forced into the lead, which produces what is known as a swedged rib. This plate is shown in Fig. 7.

Forming: The plates having been mechanically developed by the above process, so as to give the desired amount of superficial area, must now be electrically formed to produce the desired depth of active material on their surfaces.

In the forming process the plates are immersed in a dilute solution of sulphuric acid to which is added a forming reagent which consists of a lead-dissolving acid or salt such as nitric acid, acetic acid or perchloric acid. Plain sheets of pure lead, known as "dummies," are placed on each side of the plates to be formed and a current from an external source passed through the solution from the dummies to the plates. The forming acid dissolves the lead from the plates to be formed, and the action of the electrolyte and the current is to re-deposit the dissolved lead in the form of a lead peroxide on the plate which is being formed.

This process converts all the plates into negatives.

Such of these plates as are intended for positive are then "set up" in the regular way with those which are intended to be negatives, after each has been burned to its respective cross-strap or bridge. Electrolyte is then added and current from an external source is passed through the cell from the former to the latter plates.

The action of the current converts the spongy lead of

Filled Plate

Grid

Fig. 8. Faure or "Pasted" Type

the former plates into positive active material or lead peroxide; that of the latter remaining unchanged.

FAURE OR "PASTE" BATTERIES

The general method of making "paste" batteries is to

stamp the plate from a sheet of rolled lead or to cast from molten lead. The plate before pasting resembles a grid or frame with intersecting vertical and horizontal cross-bars, the edges of which are so shaped as to tend to hold the "active material" to the plate.

Faure or "Paste" Positive Plates: The "active material" for positive plates consists of red lead mixed with a solution of dilute acid to form a plastic "paste." The plate or grid is then pasted with this mixture and allowed to stand for several days to dry; or to hasten the drying the plate is placed in an oven.

The plates are then immersed in an acid bath of electrolyte, and current is passed through them at a low rate for several days, causing the lead "paste" to be converted into peroxide of lead.

Faure or "Paste" Negative Plates: The negative plate is made similarly to the positive plate, the "paste," however, being made of Litharge only. After drying the plate is placed in an acid bath, current being passed through the plate at a low rate reducing the "paste" to "active material" or spongy lead.

The chief advantages of the "pasted" battery over the Planté type are its low first cost and light weight. The chief disadvantage in the "paste" has been its much shorter life, although improved generator regulating apparatus, together with lower discharge current required, due to the use of Mazda high efficiency lamps, have been the means of reviving this particular type of battery for Train Lighting Service.

EDISON STORAGE BATTERY

The Edison Storage Battery differs materially from all other types in theory and characteristics in that it has an alkaline instead of an acid electrolyte and nickel oxide and iron for active materials instead of lead peroxide and spongy lead. The absence of acid permits the cell to be contained in a steel can instead of a rubber jar or lead lining. Its chief value lies in its light weight, rugged construction and freedom from ordinary storage battery diseases. It may be subjected to vibration, concussion and remain in a charged or discharged condition indefinitely without injury.

Positive Plate: Each positive plate type "A" is composed of thirty perforated nickeled steel tubes, each reinforced by equidistantly spaced steel rings and filled with seven hundred alternate layers of nickel oxide and pure metallic nickel flakes. They are mounted on a nickeled steel grid in two rows of fifteen tubes each.

Negative Plate: Twenty-four rectangular pockets of perforated nickeled steel, containing iron oxide, each secured to nickeled steel grid compose a negative plate of type "A" cell.

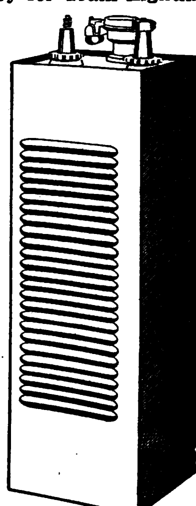


Fig. 9. Type A-8H Cell, Completely Assembled Ready to be Connected Up

Fig. 10. One of the Positive Electrodes

Fig. 11. One of the Negative Electrodes

Electrolyte: The electrolyte is a 21% solution of potassium hydrate (caustic potash) to which is added a small amount of lithium hydrate. The normal specific gravity, which does not change over a long period, is 1.210° at 60° Fahrenheit.

Insulation: The alternate positive and negative plates are insulated from each other by vertical hard rubber pins or rods, equidistantly placed. Molded hard rubber "ladders" secure the plates at their edges and insulate the whole from the containing can. A sheet of hard rubber is placed between the end negatives and can. A molded hard rubber "stool" forms the bottom support for the plates.

Containing Can: The containing can is of nickeled steel, all seams being welded by the autogenous process, "oxygen-acetylene flame." After the elements have been placed in the can, the top is welded on. The poles are insulated from the can and the mechanical joint made gas and liquid tight by special stuffing boxes.

Fig. 12. Type A-8H Cell, Assembled but Entirely Removed from Container

Filling Aperture and Gas Vent: The top of the can supports a combination filling aperture and gas valve, the construction of which is apparent from the cut, Fig. 13.

Connectors: The poles are tapered to fit the terminal lugs and are brought to intimate contact with same by setting up on the nuts or top of the poles.

Trays: The cells are assembled in wooden trays, each cell being supported by a steel cradle secured to the tray. Steel hold-down straps maintain the cells in position even when subjected to violent concussion.

Fig. 13. Top of Edison Cell. Filling Aperture and Check Valve Open for Adding Distilled Water

Charging: The normal charging rate of the standard car lighting cell Type A-8H, 300 ampere-hour capacity is 60 amperes for seven hours. The cells may be "boosted" for an hour at 120 amperes, for one-half hour at 180 amperes or for fifteen minutes at 240 amperes if necessary. They may be charged at any point of discharge, or discharged at any point of charge without detriment. The maximum P. D. at the cell poles on charge at normal rate is 1.85 volts, although in car lighting practice a cell terminal voltage of 1.8 is generally found to prevail. Therefore the treminal charging voltage for a 32-volt set consisting of 25 cells will be 45 volts and for a 64-volt set with 50 cells, 90 volts.

Discharge: The normal discharge rate for eight hours is 37½ amperes, and for five hours 60 amperes. The average voltage per cell at the eight-hour rate of discharge is 1.24 volts per cell and for a five-hour rate of discharge is 1.2 volts per cell.

Care: The Edison Company recommend the following:

1. Addition of distilled water at intervals to keep the electrolyte above the tops of the plates.

2. Renewal of electrolyte every eighteen months to two years.

3. Keeping the cells externally clean and battery compartment clean and dry. The Edison Company advise that the plates do not shed active material or buckle, and further, there are no separators to renew. The cell does not sulphate under any condition of service and nothing approximating sulphate can exist.

Weight: The weight of a car lighting cell, 300 ampere-hour capacity, Type A-8H is 35 pounds.

Characteristic Curves: Typical charge and discharge curves of the Edison cell are shown in Fig. 14.

Chemical Reaction: Starting with iron oxide in the negative, green nickel hydrate in the positive, and potassium

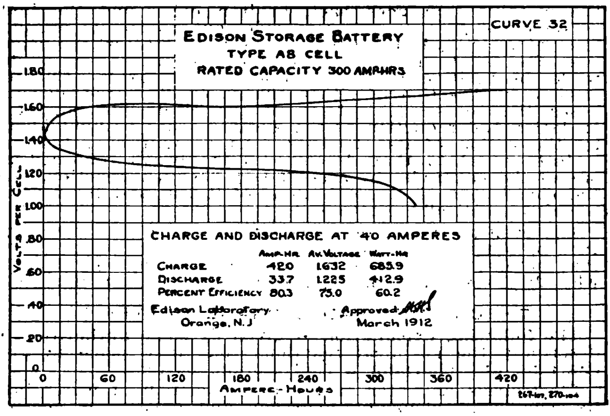


Fig. 14

hydrate in solution, the first charging of a cell reduces the iron oxide to metallic iron while converting the nickel hydrate to a very high oxide black in color. On discharge

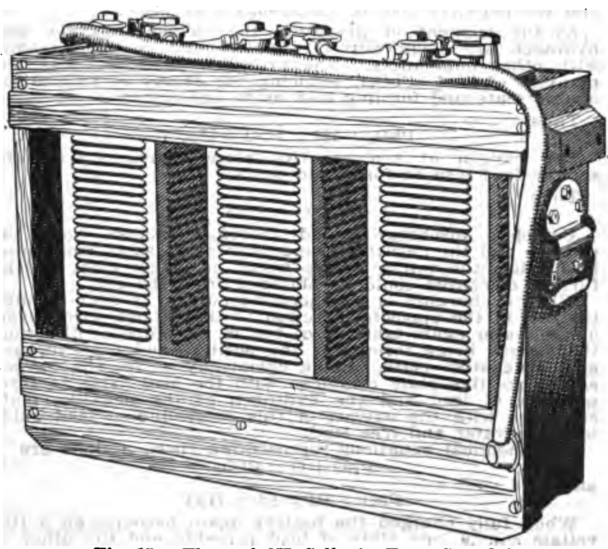


Fig. 15. Three A-8H Cells in Tray Complete

the metallic iron goes back to iron oxide and the high nickel oxide goes to a lower oxide, but not to its original form of green hydrate. On every cycle thereafter, the negative charges to metallic iron and discharges iron oxide, while the positive charges to a high nickel oxide. Current passing in direction of either charge or discharge, decomposes the potassium hydrate of the electrolyte, and the oxidation and reduction at the electrodes are brought about by the action of its elements. An amount of potassium hydrate equal to that decomposed is always reformed at one of the electrodes by a secondary chemical reaction, and the consequence is there is none of it lost and its density remains practically constant.

The eventual result of charging, therefore, is a transference of oxygen from the iron to the nickel electrode, and that of discharging is a transference back again. This is why the Edison is sometimes called the "oxygen lift" cell.

THEORY OF LEAD STORAGE BATTERIES

The following explanation is given by some authorities in describing the chemical reactions that take place in discharging and charging a lead storage battery.

Electrolysis of water or the decomposition of water into its component elements, hydrogen and oxygen, is accomplished by slightly acidifying the water and then passing current through it. This is what happens in a storage battery. Upon discharge the current passing through the battery decomposes the water of the electrolyte, liberating hydrogen at the positive and oxygen at the negative pole. In this case the positive pole is the peroxide of lead plate and the negative pole is the spongy lead plate.

At the moment of liberation the elements oxygen and hydrogen are chemically very active and combine readily with other substances. The hydrogen combines with the peroxide of lead (PbO_2), reducing the degree of oxidization of this plate and forming lead oxide and water.

Thus

$$PbO_2 + 2H = PbO + H_2O$$

The oxygen at the negative plate combines with the spongy lead also to form lead oxide.

Thus

$$Pb + O = PbO$$

Complete discharge would therefore change both the positive and the negative elements into the same compound, lead oxide, the voltaic couple would no longer exist and no further discharge could be obtained from the cell.

When a charging or regenerating current is sent through the cell in the opposite direction to that above, electrolysis of the water again takes place but in the opposite direction, the oxygen being formed at the positive and the hydrogen at the negative plate. Being chemically active the oxygen at the positive plate combines with the lead oxide to form peroxide of lead and the hydrogen at the negative plate combines with the oxygen of this compound of lead oxide to form water and free lead.

The chemical equations representing these actions are

$$PbO + O = PbO_2$$

and

$$PbO + 2H = Pb + H_2O$$

When fully charged the battery again becomes an active voltaic couple, one plate of lead peroxide and the other of spongy lead.

Lead oxide (PbO) cannot exist as such in the presence of sulphuric acid. As fast as either plate is changed into lead oxide (PbO) by the process described above the sulphuric acid in the electrolyte turns them into lead sulphate ($PbSO_4$), the SO_3 radical in the sulphuric acid combining with the lead oxide. This process is called sulphatation. The chemical reaction itself is independent of the passage of current and will take place whenever lead oxide is immersed in sulphuric acid, lead and lead peroxide being very slightly affected by it.

In his book on Storage Battery Engineering Mr. Lamar Lyndon states that while the foregoing may be a very simple attractive theory, it is upset by thermodynamic considerations, since lead oxide cannot be changed chemically to lead sulphate without the liberation of heat. This heat represents all or a large portion of the energy in a storage battery and since this energy is returned it is clearly impossible that the simple chemical combinations take place. It is now generally conceded that the change from spongy lead and lead peroxide to lead sulphate is direct and does not pass through any intermediate stage. The rest of the theory advanced, however, is quite true.

Lead sulphate is white in color and possesses such a high electrical resistance as to be practically useless as a conductor. If the battery should become completely discharged and the elements turned to lead sulphate, it would be practically useless, as the reduction from lead sulphate to either pure lead or lead peroxide is especially difficult if not impossible. A battery should therefore never be discharged below a certain limit governed by the amount of sulphate formed. This should be very small as enough spongy lead or lead peroxide must remain to keep down the resistance and permit the passage of current for the regeneration of the cell. Furthermore, the formation of too much sulphate is likely to cause breaking or buckling of the plates or the forcing off of the active material due to increase in its volume caused by the change from Pb or PbO_2 to $PbSO_4$.

Chemical changes take place in the electrolyte during charge and discharge causing variations in its density. During charge, the SO_3 in combination with the active material is given up to the liquid forming sulphuric acid and increasing the density of the electrolyte. On discharge, the converse action takes place, the SO_3 is taken up by the Pb and PbO_2 to form $PbSO_4$, decreasing the weight and density of the electrolyte.

The following reversible chemical equation explains these chemical reactions:

$$\xleftarrow{\text{charge}}$$

$$\text{(a)}\quad PbO_2 + H_2SO_4 = PbSO_4 + H_2O + O$$

$$\text{(b)}\quad Pb + H_2SO_4 = PbSO_4 + H_2$$

$$\text{(c)}\quad \text{(a)} + \text{(b)} = PbO_2 + Pb + 2H_2SO_4 = PbSO_4 + H_2O$$

$$\xrightarrow{\text{discharge}}$$

Equation (a) and (b) show the chemical reactions at the positive and negative plates respectively and (c) the combined effect. Equation (c) is the fundamental equation of the lead storage battery.

The above equations show that on charge both the negative and positive plates start as lead sulphate ($PbSO_4$) and are turned to lead and lead peroxide by combination with the dissociated gases of the water in the electrolyte. The SO_3 liberated combines with the water in the electrolyte to

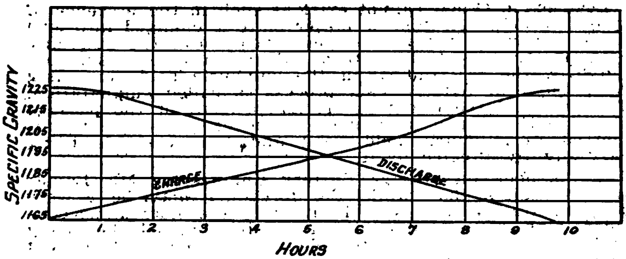


Fig. 16. Variation of Specific Gravity upon Charge and Discharge

form sulphuric acid (H_2SO_4). Reading the above equation from left to right shows the action upon discharge, the lead (Pb) and lead peroxide (PbO_2) combining with the sulphuric acid and forming lead sulphate ($PbSO_4$) and water (H_2O).

There are many other intermediate reactions and by-products of decomposition than those given by the foregoing equation but they strictly belong to the chemistry of storage batteries and are therefore outside the scope of this book.

The voltage of any battery is dependent upon the character of the metals or metallic compounds forming the plates and upon the density or concentration of the electrolyte. The voltage of the lead storage battery is that of spongy lead against lead peroxide as long as any particles

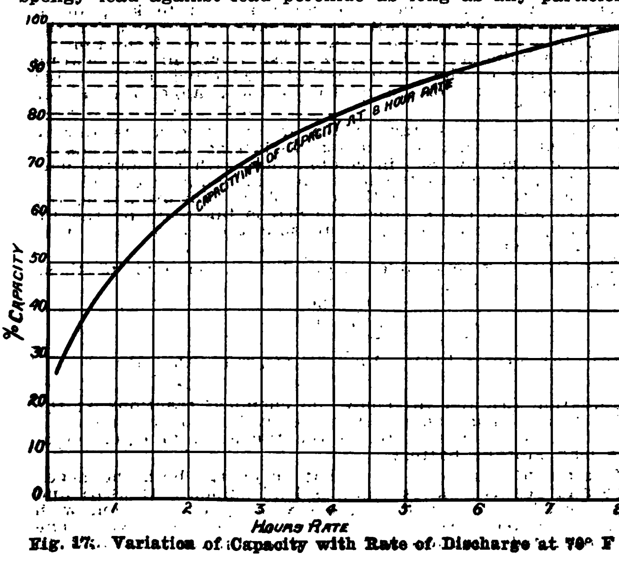


Fig. 17. Variation of Capacity with Rate of Discharge at 70° F

of these materials are on their respective plates. If the elements only are considered and the density be maintained constant, the e. m. f. of a battery should theoretically remain constant up to the point of reduction to sulphate of the last traces of spongy lead or lead peroxide, and it should then fall suddenly to zero. In reality the voltage falls gradually from the beginning to the end of the discharge, due to several causes, the chief of which is the variation in acid density. Fig. 16 shows this variation of density with normal charge and discharge rates.

The area of the plates upon which the electrolyte acts determines the rate of current at which a battery may safely be discharged. The active area in any cell is equal to the sum of both sides of the positive plates, both sides of the plates being active.

The unit of storage battery capacity is the ampere-hour. The total capacity is designated by the product of the rate of discharge in amperes by the time during which the discharge lasts, the battery being considered completely discharged when a minimum of 1.8 volts per cell is reached. There is a considerable variation, however, with the rate of discharge, as is shown in Fig. 17, being less at rapid than at slow rates. When referring to train-lighting batteries the eight-hour discharge rate is generally considered normal. For example, a fully charged battery having a capacity of 280 ampere-hours will discharge 35 amperes continuously for eight hours without the voltage falling below 1.8 volts per cell.

As shown above SO_3 is abstracted from the electrolyte upon discharge. If it was all taken from the sulphuric acid water only would be left, in which case the voltaic couple would show an e. m. f. of only about 1.46 volts.

If, after discharge has taken place, the battery is allowed to stand on open circuit for a few minutes, it will recuperate to some extent and its voltage will rise. This can be explained by the fact that the SO_3 is taken up from the acid only at those points and surfaces where the acid is in contact with the plates. As the SO_3 is removed the density of the acid is decreased, causing a circulation of the electrolyte, fresh acid taking the place of that which is exhausted. The chemical action, however, is slowest in the minute pores of the plates, where circulation is most difficult. When the cell is allowed to stand on open circuit time is allowed for the water or highly dilute acid in the pores to diffuse out into the denser acid, and the latter to enter. It is evident that the more porous the active material and the better the circulation of the electrolyte, the less will be the drop in voltage as discharge proceeds.

Fig. 18 shows the voltage changes upon charge and discharge of the ordinary type of cell. It is seen that the voltage during charge stays reasonably constant around 2.3 volts for a considerable period of time, a continuous and relatively rapid rise to about 2.6 volts occurring toward the end of charge. It is probable that intermediate chemical changes begin to take place at the point where the curve begins to rise rapidly, and also that gas is produced and the effects of polarization become more marked.

Upon discharge the voltage curve shows like form to that of charge except in the reverse direction. It drops rapidly at the beginning of discharge to about 2 volts, at which point it remains very nearly constant until near the end of discharge, when it begins to fall rapidly, and if the discharge be continued, would drop quickly to zero. This sudden fall in voltage is due to a number of causes, the most important of which is the formation of lead sulphate

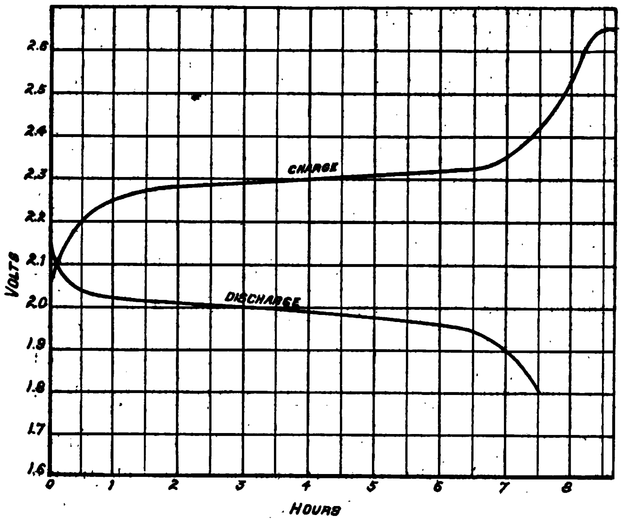


Fig. 18. Voltage Curves of Charge and Discharge

on the surface of the plate, preventing access of the electrolyte to the inner pores of the active material. The electrolyte which is enclosed in these pores rapidly turns to water by reason of the abstraction of SO_3 from the H_2SO_4.

The maintenance of the voltage, and consequently the capacity of the cell, is dependent upon the condition of both the positive and negative plates. If one be fully charged or fully reduced and the other only partially charged, the capacity of the cell would equal only that of the least efficient plate; the battery would be quickly discharged and the voltage curve would fall off rapidly. It is necessary, therefore, that both the positive and negative plates be completely charged in order that the cell have its full capacity. The voltage of the cell is not always an indication of the state of the charge and in order to determine the condition of the two plates, it is necessary to test them independently. For this purpose a piece of metal, either zinc or cadmium, preferably the latter, is immersed in the electrolyte and the voltage observed between it and both the positive and negative elements.

The cadmium used must be free from impurities and its surface should never be scraped bright. It should rather be "aged," that is, slightly oxidized, for the reason that there is a difference of potential between bright cadmium and cadmium oxide. The bright surface oxidizes so quickly that it would be necessary to scrape the test piece clean after each reading, if comparable results were to be obtained by the use of the bright metal.

In making this test care should be taken to see that the cadmium does not come into contact with either of the

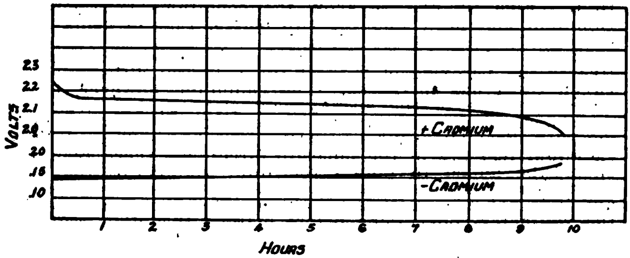


Fig. 19. Cadmium Curves on Discharge

plates or connections. The best method to prevent this is to cover the test piece with rubber in which a number of holes have been punched to admit the electrolyte.

Upon discharging a cell down to 1.8 volts the voltage between the cadmium test piece and the positive plate should not be lower than 1.98 and between the cadmium and negative plate not higher than .18, the cadmium being positive to both elements in the voltaic sense. When both readings are in the same direction the cadmium negative reading of .18 is subtracted from the cadmium positive reading of 1.98 giving 1.80, the voltage of the cell.

The above readings must be made while the cell is discharging at the normal rate. When fully charged and with the normal charging current still passing, the voltage between the cadmium and the positive plate should be about 2.35 and between the cadmium and the negative element from .18 to .20. The cadmium is positive to the positive plate and negative to the negative element. In other words, voltaically considered, the negative becomes more highly electro-positive, and instead of being positive to the cadmium, as it is when discharging, it becomes negative

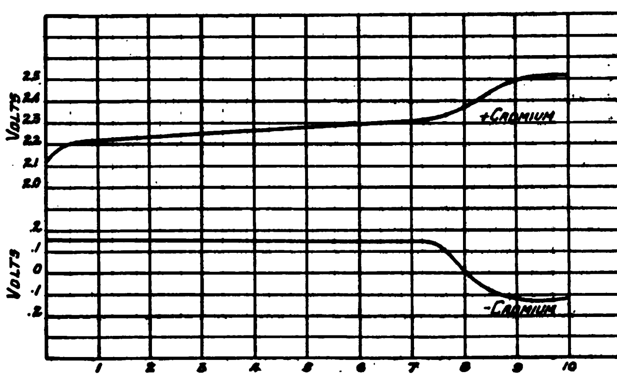


Fig. 20. Cadmium Curves on Charge

to it. Figs. 19 and 20 show the conditions between the cadmium test piece and the two plates, Fig. 19 being that of discharge and Fig. 20 being that of charge.

At the end of charge, Fig. 20, the cadmium is still positive to the peroxide plate, and the potential difference between them has increased. The cadmium, however, is no longer positive to the spongy lead element, but negative, as shown, and the voltage between them reads in the opposite direction. Whenever the voltage readings in the cadmium test are in the opposite directions, these readings should be added to obtain the total voltage of the cell. When both cadmium readings are in the same direction and it is not necessary after making one reading to reverse the voltmeter connections before making the other reading, the voltage of the cell is equal to their difference.

In making all these readings, the sum or difference of the two cadmium readings should equal the observed voltage of the cell. It is somewhat difficult in actual practice, however, to check these readings exactly, due to the small voltmeter deflection obtainable between the cadmium test piece and the negative element.

Factors Influencing Voltage: In addition to the condition of the two elements, the voltage of a cell is dependent on the density of the electrolyte, the internal resistance and the temperature.

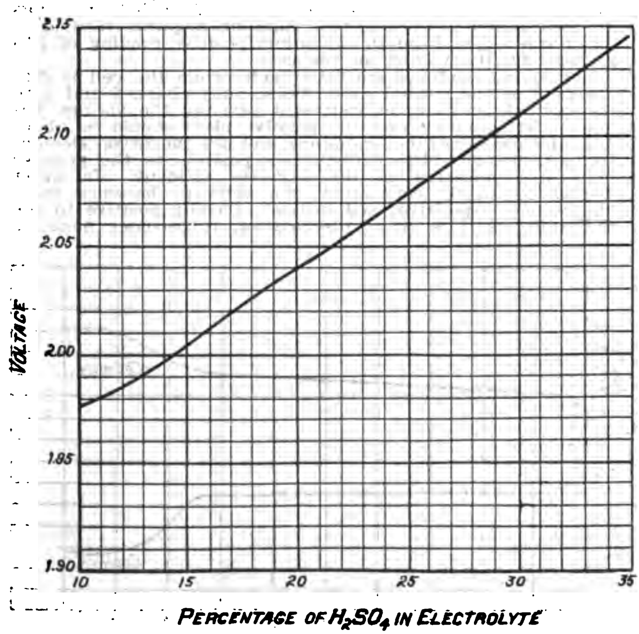


Fig. 21

Fig. 21 is a curve showing the variation of voltage with variation in electrolyte density.

Change of the internal resistance varies the internal drop and consequently changes the voltage of the cell. The effect, however, is always so small as to be negligible in practice.

Influence of Temperature: The changes in ampere-hour capacity, voltage on charge and discharge, internal resistance and efficiency with variation in temperature are surprisingly great.

Experiments show that the charging voltage decreases, and on discharging the voltage increases with rise in temperature.

The internal resistance decreases with rise of temperature.

The explanation of these heat phenomena seems to lie in the increased porosity of the active material due to expansion under the action of heat, and the increased circulation of the electrolyte giving a more efficient use of the active material and the combining SO_3.

The decrease in the charging voltage may be due to reduction of polarization e. m. f. by the driving off of the adherent and occluded gases. Possibly other causes may contribute to the decrease.

The capacity variations that will take place will depend for their absolute values on the thickness of the layer of the active material, its character, and its disposition, and the discharge rate. It is evident that the more porous the active material at normal and the lower the discharge rate, the less will be the increase in capacity for higher temperature.

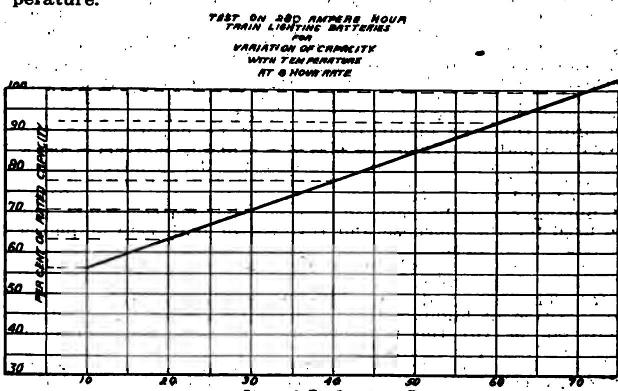


Fig. 22.

Fig. 22 shows the variation in capacity with temperature in a standard 280 ampere-hour train-lighting battery.

Diseases of Batteries and Their Remedies: Lead storage batteries are subject to various diseases. It is most important that the storage battery man have a definite working knowledge of each of these together with the proper

remedies in order that the proper life and capacity be efficiently obtained.

The principal diseases to which such a battery is subject are:

1. Loss of capacity.
2. Corrosion of plates.
3. Fracture and buckling.
4. Shedding of active material.
5. Sulphatation.
6. Reversal of negative plates.
7. Internal discharge.
8. Hardening of negatives in air.
9. Loss of voltage.

(1) Loss of capacity may arise from several causes, such as clogging of the pores of the lead sponge with sulphate or impurities, contraction of the pores, loss of active material from the plate, formation of a layer of sulphate between the plate and the active material, or insufficient amount of electrolyte.

When the negative plate shows a decreased capacity, and exhibits no sign of sulphatation or no loss of material, it will be generally found that the material has shrunk or the pores are clogged with sulphate and impurities. This seldom happens on train-lighting batteries, but when it does, the plates must be rejuvenated by reversing.

When the plates are to be rejuvenated the battery is first discharged, the negative elements removed and placed in a bath of sulphuric acid of 1.200 density. They are then connected up for the passage of current in the reverse manner to that in which they were normally intended to be connected. "Dummy" plates of plain sheet lead about $\frac{1}{16}$ inch thick should be used as cathodes. When current is passed through the plates the spongy lead is first turned to lead oxide (PbO), and then as the action continues, to peroxide of lead (PbO_2). When this final change is accomplished the bath is renewed by the substitution of fresh acid and the current is again reversed. Fresh acid is used in order that the impurities may not be deposited on the negative plates. When the plates are finally converted back to spongy lead and reassembled with the positive plates it will be found that the capacity of the battery has increased and been brought up to nearly its original condition. If dummies can be secured the positive plates should not be used for this purpose and reversal of both sets of plates should be avoided.

(2) Corrosion of plates may occur from either of the two following causes:

(a) The chemical action resulting from electrolytic decomposition of highly dilute acid in the pores of the active material, or (b) the presence of lead dissolving acids or their salts in the electrolyte.

There is no remedy for the first condition, which occurs in every cell if the discharge be carried too far or if the plates have a thick layer of active material when the discharge rate is high. The presence of lead dissolving acids in the electrolyte will be manifested by a continuous increase in capacity, showing the forming process is still going on attacking the plates. The obvious remedy is to change the electrolyte, and substitute fresh acid free from injurious substances. In addition to these effects, there is a normal slow disintegration due to the action of the acid and products of decomposition. It cannot be entirely stopped as it is the natural depreciation to which the plates are subject. It can

be partly remedied, however, by decreasing the density of the electrolyte.

Corrosive action of liquids upon solid substances immersed in them takes place with the greatest rapidity at the surface of the liquid. Battery plates which project above the electrolyte go to pieces at its surface before the submerged parts have greatly depreciated. This effect can be greatly reduced by keeping the plates covered with liquid and making the lugs, which pass from the plates out to the terminals, of thick, dense lead.

(3) Fracturing and buckling are due to excessive or unequal expansion. They indicate that the discharge was carried too far, that the rate was too rapid, or that the current distribution over the plate was not uniform and certain portions were too far or too rapidly discharged. It will be seen that the buckling can take place even at normal current rates if the formation of active material, or its application, be not uniform over the exposed surface. Should buckling occur under these conditions it would indicate a defective plate.

Buckling on rapid rates of discharge may be due to slight inequalities of distribution of active material, together with differences in electrolytic densities which occur in deep tanks. Discharge at high temperature may also cause buckling, due to the increase in capacity and the consequent formation of sulphate, the bulk of the active material being more greatly changed than if the discharge had taken place at a low temperature, and less capacity had been delivered.

There is no remedy for troubles due to defective plates save to keep the electrolyte circulating, refrain from discharging too far and keep excluded from light and air.

(4) Shedding of active material cannot be prevented if it is improperly formed or applied, or if it is of such a character that it easily disintegrates or loosens from the grid. With good active material shedding occurs, however, due to expansion and contraction which the grid cannot follow, to the rapid release of gases when charging at high rate, or upon overcharging. When shedding takes place in a greater degree than ordinary usage and depreciation call for, the following rules should be observed:

Charge at low rates; do not overcharge, i. e., do not go above 2.6 volts; do not discharge down too far, say below 1.8 volts.

(5) Sulphatation of the injurious kind differs from the normal sulphatation of charge and discharge, in that it is almost irreducible, causes shedding of active material, buckling, loss of capacity, increase of internal resistance with consequent reduction of efficiency, and increase of temperature with passage of current.

The causes of over-sulphatation are over-discharge or rapid discharge, either of the entire mass of active material or only certain portions of it, and the injurious effects are those which rise from great increase in resistance and excessive expansion and contraction, which are mentioned above.

The causes of over-discharge are: (a) Intentional, through external circuit; (b) local action and leakage; (c) loosening of active material which discharges but is not traversed by current on charge and consequently becomes over-discharged; (d) short circuits between plates.

Excessive discharge rates also tend to form a layer of sulphate on the plate preventing the electrolyte from reaching the inner recesses of the active material. This causes the discharge action to take place only on the outer layer

and results in an over-discharge of this surface and the formation of non-reducible sulphate.

When for any reason the active material is not in close contact with the grid, the electrolyte is able to penetrate between the two. Obviously the action on discharge will take place most rapidly at this point and a layer of sulphate will be formed on the surface of the active material next to the grid. When the lead or lead peroxide is sufficiently reduced, this layer of sulphate becomes non-conducting and current cannot be forced between the plates except at high voltage. The above process of sulphatation is augmented if either the acid density or the temperature is high.

In addition to these injurious effects, those previously mentioned, due to change of volume of the active material, and buckling, generally result.

Local action and short circuit between the positive and negative elements will both cause over-discharge and the consequent injurious sulphatation.

Lead sulphate is white in color and the manifestation of its presence is the gradual lightening in color of the affected parts. If the process is continued eventually flakes of pure white sulphate will be formed over the plates or those portions affected by the action.

The best remedy for sulphated plates is a charge and discharge, the rate depending on the degree of sulphatation. When the plates are only slightly affected they should be subjected to a long slow charge and discharge, at a rate of about one-half normal. When the plates are badly sulphated they should be subjected to a long heavy charge and discharge at a rate not to exceed twice the normal rate. Care must be taken that the temperature of the cells does not exceed 105° F.

In case only one cell is affected it should be taken out of the set and treated separately. If either the positive or negative plates alone are affected they should be removed from the cell, set up with dummy plates of lead and treated as above.

The electrolytic density and the temperature should also be within the prescribed limits. While neither of these factors directly cause sulphatation, they greatly assist the real causes and accelerate and augment this injurious action.

Short circuits should be prevented by keeping the cells cleaned out and never allowing the sediment, which is a conductor, to accumulate in the bottom or between the plates on the separators. Also, the separators and spacing of the plates should be given occasional attention.

When an excess of sulphate once forms, several cycles of charge and discharge are necessary to bring the battery up to its normal capacity. The first charge should always be a prolonged overcharge.

(6) The reversal of negative plate occurs on account of loss of capacity of one cell, or because some cell or cells are not in the same charged condition as the balance of the set, the defective cell or cells being overpowered by the large capacity cells, and reversed. The remedy for this is the removal of the defective cells in order that they may separately be brought to the proper charged condition. The cause of the loss of capacity of these particular cells must be ascertained and corrected as otherwise the reversal will again occur.

A cell in series with other cells may be overcharged by cutting it in on charge and out on charge.

(7) "Local Action" is the term applied to the internal discharge that takes place between the active material and the grid or between the active material and metallic im-

purities on the same plate. It occurs most frequently at the negative or spongy lead plate and is frequently due to impurities in the electrolyte.

The negative plate, when charged, should never be permitted to become dry or exposed to the action of the atmosphere. Oxidization of the sponge lead will take place very quickly, with the result that the plates become very much heated and harden rapidly and it is then very difficult to reduce the active material to sponge lead. The remedy is to use pure electrolyte and keep the plates well covered. Local action often results in filling up the pores of the sponge lead with deposited impurities and sulphate, thereby reducing the capacity.

If the negatives are of such character as to stand reversal they may be revitalized by the method described under the heading "Loss of Capacity."

(8) Hardening of negatives in air proceeds from oxidization and heating and leaves the spongy lead in a difficult condition to reduce to its proper form. The only method is by a continued overcharge. If possible this should be done, using dummy positives as the battery positives would very likely be injured if subjected to the amount of overcharge necessary to remedy this condition. If, however, conditions are such as to require an immediate remedy and no dummy positives are available, the battery positives would probably be used without serious injury, providing the overcharging is done at not more than one-half the normal rate.

(9) Loss of voltage is of frequent occurrence. In a battery of any size there are generally one or more cells that show an e. m. f. less than normal and at times they may reverse their polarity. This diminished e. m. f. is due to the abnormal amount of sulphate in the active material, which must be reduced and its cause ascertained and corrected as explained in the above paragraph on sulphatation.

Electrolyte: The electrolyte used on storage batteries of the lead lined type consists of dilute sulphuric acid having a specific gravity of from 1.200 to 1.300, depending on the amount of electrolyte and the construction of the cell. It should be free from all impurities such as hydrochloric, nitric or acetic acids, iron, arsenic, antimony, copper and mercury, or the slightest trace of platinum, and by analysis must not exceed the following:

Arsenic	Trace
Manganese	Trace
Iron	0.003%
Chlorine	0.001%
Nitrogen, any form	0.01%
Copper	0.002%
Sulphurous acid	None
Organic matter	None

The following is a description by one of the leading battery authorities of the test for the various impurities which are liable to be found and which are injurious to the battery:

Iron: The impurity causing the most trouble in car lighting work is iron, and when batteries are cleaned the acid removed should be tested to ascertain whether or not it should be used again. Test should be made as follows:

Commercial acid to be mixed with an EQUAL VOLUME of a 5% solution of ammonia sulphocyanide which can be obtained from druggists and should be made as follows:

Ammonia sulphocyanate cryst.	1 oz.
Water	20 oz.

If iron is present the solution will turn a red color, the shade of same being dependent upon the percentage of iron present. This should be compared with two sealed test tubes, one containing electrolyte with .01% of iron and equal portion of reagent and one containing electrolyte with .005% of iron and equal portion of reagent. Of the sealed test tubes, that having the .01% of iron will be the darker color and if the color of the acid and reagent under test is darker in color than this, the acid should not be used.

Copper: Add a solution of ammonia to a portion of the electrolyte. If a bluish-white precipitate appears copper is present in the electrolyte.

When an excess of ammonia is added and the liquid becomes alkaline, the precipitate disappears and the liquid becomes a dark blue color.

Mercury: The presence of mercury in the electrolyte is indicated by a black precipitate when lime water is added, or by an olive green precipitate when a solution of potassium iodide is added.

Arsenic: Pass sulphuretted hydrogen (H_2S) through a warm dilute solution of electrolyte. If a yellow precipitate forms, it is probably arsenic but may be sulphur, caused by oxidation of H_2S by ferric salts or nitrates. Take two test tubes and put a portion of the yellow liquid in each. Add to one ammonium sulphide, to the other ammonium carbonate. If the yellow precipitate is an arsenic compound it will be dissolved by ammonium sulphide, but not by ammonium carbonate.

Nitric Acid. Tests: (1) Make in a test tube a solution of ferrous sulphate (Fe_2SO_4) and add sulphuric acid (H_2SO_4). Shake well and allow to stand until cool; then without mixing, carefully pour in the solution to be tested and lightly tap the side of the tube. If nitric acid or nitrates are present, a brown ring will be formed where the liquids meet, and which disappears upon shaking.

(2) A solution of a nitrate with sulphuric acid and a few bits of copper will give off reddish fumes.

Hydrochloric Acid. Test: To the solution add silver nitrate ($AgNO_3$). This gives a white precipitate, silver chloride ($AgCl$), insoluble in nitric acid but soluble in ammonia.

Acetic Acid. Test: Add ammonia (NH_4OH) to the solution until it becomes neutral; then add ferric chloride (Fe_2Cl_6). If the solution turns red and is afterwards bleached by the addition of hydrochloric acid (HCl) there is acetic acid present.

Inspection: A pint bottle for test should be made up from each shipment of acid and contain a portion of acid from each carboy; this should be sent to some competent chemist for test and none of the consignment used until a report of its acceptance has been received from the chemist.

Specific Gravity: The density of the electrolyte is dependent upon the proportions of acid and water; in other words, it depends upon the degree of dilution of the acid, and is measured by means of an hydrometer.

The hydrometer consists of three parts: (1) The upper part—a graduated stem or fine tube of uniform diameter; (2) a bulb or enlargement of the tube, containing air; (3) a small bulb at the bottom, containing shot or mercury, which acts as a ballast and causes the tube to float in an upright position.

The density is expressed in terms of specific gravity; i. e., the ratio of the density of the liquid to pure water, or in terms of some arbitrary scale such as the Baume, Twaddles, etc. For car lighting service this must be main-

tained at from 1210 to 1225; a specific gravity of 1220 being considered the best.

When testing a cell for the specific gravity of the electrolyte with a view to correcting same, the following method should be pursued: Fill the cell with water and place on charge; when fully charged test the specific gravity, and add as much acid or distilled water as may be necessary to bring the specific gravity of the electrolyte to 1220.

As explained in preceding paragraphs, the electrolyte must be kept above the tops of the plates and as much higher as the construction of the tank will permit. As it is essential that the electrolyte be free from all impurities only distilled water should be used in diluting the acid.

Water obtained by condensing steam from a steam boiler should not be used, as it is liable to contain oil or chemicals used in purifying the water for boiler purposes. The water should be condensed in a copper still, and a copper or lead pipe or a rubber hose should be used for the purpose.

Whenever the electrolyte is found to be impure due to the presence of any metal other than lead or of any acid other than sulphuric, it must be immediately drawn off and new electrolyte applied.

The purchase of an acid of low concentration, say 1200 specific gravity, is much more convenient than an acid of higher specific gravity and diluting, and it is claimed that it is superior to that obtained by dilution on account of being more carefully prepared.

When diluting an acid, the acid should always be slowly poured into the water, and not the water into the acid. The reason for this is that a chemical combination is formed which liberates heat, thus raising the temperature of the electrolyte, and if the water is poured into the acid the action is more rapid than if the acid be poured into the water.

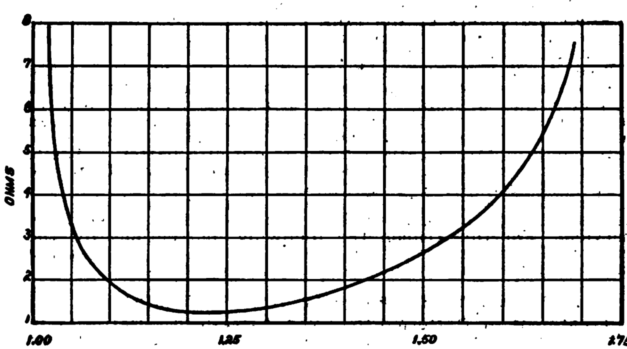


Fig. 23. Resistance of Sulphuric Acid per Cu. Cm.

After dilution the electrolyte must be allowed to cool before using. It will be found that upon cooling the specific gravity is greater than when hot, but this can be lowered to the proper value by the addition of a little distilled water.

The density of the electrolyte governs to a great extent the operation of the battery. If too dense, the electrolyte

tends to evaporate more readily, sulphatation is facilitated and the plates are liable to rapid depreciation.

The specific resistance of sulphuric acid is least at a density of about 1260, rising if the density be either increased or decreased. A curve showing the variation of resistance with specific gravity is shown in Fig. 23.

General Instructions: Batteries must never be allowed to stand in a discharged condition, but should be put on charge as quickly as possible after discharge.

Reading of the voltage of individual cells should be taken every two weeks with a voltmeter having a three-volt scale, such readings being taken with the battery on discharge, subsequent to a full charge. Each cell should read at least two volts. If any cell reads below this, action should be taken at once to determine the cause of the trouble and to correct same.

Keep the plates covered with electrolyte.

Readings of the specific gravity of the electrolyte of the individual cells should be taken once a month, when each cell is in a fully charged condition. The electrolyte should then have a specific gravity of 1215 to 1225. If the specific gravity of the electrolyte is outside these limits it should be corrected by adding acid or water as may be required to bring it to 1220 degrees.

Never allow charged negative plates to become heated by standing in air; submerge or sprinkle them with water until they show no tendency to heat.

In setting up batteries, after cleaning or repairing, see that all separators, bottom insulators, and hard rubber insulating sheets are in place. Particular attention should be paid to connecting the battery up properly, positive to negative.

Use distilled water only.

Wait until the electrolyte cools before using.

Keep the covers of the tank clean.

Keep the connections clean and tight.

When cleaning battery, paint all tanks.

The foregoing article treats to some extent on the theoretical side of the battery and the reader must not form the idea that a storage battery is a very delicate piece of apparatus and that all of the tests and suggestions given are absolutely necessary and must be strictly adhered to in order to obtain a satisfactory life out of a battery. While "laboratory conditions" undoubtedly tend to lengthen the life, such conditions cannot exist in practical operation; nevertheless, a little intelligence and care in handling batteries will go a long way toward obtaining satisfactory service. For this reason the following instructions for the care and maintenance of batteries, by one of the leading storage battery manufacturers, are given.

PUTTING THE BATTERY INTO COMMISSION

Treatment of Batteries Received Assembled: Batteries in lead-lined tanks are usually shipped fully charged ready for service. Before being placed in commission each battery should be thoroughly inspected and any loss of electrolyte replaced with acid of 1225 specific gravity. The battery should then be given a freshening charge at the finish rate, until the voltage and specific gravity have remained at a maximum point for two hours. At this time all the cells should be gassing freely and the battery is ready for service.

Assembling: If the batteries are received knocked down, they should be carefully unpacked and assembled. Place

the elements on edge on a convenient bench or table with the face of the plates at right angles with the surface of the table. Put in the separators between each plate, after which the elements should be carefully inspected to see that no separators have been omitted. Place the hard rubber sheet linings and the porcelain rests in the lead lining. Four pieces of sheet tin are bent down six inches over the hard rubber lining. These pieces will prevent breakage of the hard rubber linings when the element is slipped into position, and are removed after the cell is assembled. The element, including the separators, is lifted up by taking hold of the connecting straps, and carefully placed in the tank.

In order to prevent the separators from sliding down it is advisable to encircle the element with a strap, which can be pulled out after the element is placed in position.

When placing the elements in the tanks, it is very essential that they all be placed so that the positive post is on the right-hand side when facing the front end of the tank.

Initial Charge: Connect the cells in series by means of temporary connections, always connecting the positive post of one element to the negative post of the adjacent element. Fill the cells with electrolyte of 1210 specific gravity, covering the plates by about one inch. Connect the positive terminal of the battery to the positive terminal of the charging source, and the negative terminal of the battery to the negative terminal of the charging source, after which the initial charge can be started at a rate equal to the finish rate. After the battery has been on charge for two hours, it is advisable to go over all the individual cells with a voltmeter in order to ascertain that the cells are connected properly and not in a reverse direction.

The charging is continued at the above rate until the specific gravity in all the cells has reached a maximum and remains at this point for at least six hours. This will take approximately from 40 to 50 hours, but the length of time should not determine the end of the charge.

The initial charge does not need to be continuous, but can be discontinued over night if necessary; but the battery should not be put into service until it has received a complete initial charge.

The specific gravity of the electrolyte at the end of the initial charge is in the neighborhood of 1225. If the cells show uneven specific gravity, the same should be adjusted and evened up at the end of the initial charge.

The temperature should be watched very carefully, and should not be allowed to exceed 110° F. When the temperature approaches this point, the charge should be discontinued until the cells have cooled down.

It is good practice to give each cell one or two discharges before putting into service.

Sealing: After the cells have been given their initial charge, they should be thoroughly inspected to see that the plates have the proper color and are in the proper condition. After this, the crown of the lead lining should be thoroughly wiped off and dried with a flame. The bushings are inserted in the hole of the cover. The holes of the bushings are painted with vaseline and the cover is placed in position, the bushings being so adjusted that they hold the cover down on the ledge provided for the same. A weight is placed in the center of the cover and the cover is sealed in. Care should be taken not to get the sealing compound too warm, as it will flow down into the cell. The

recess in the cover is filled with compound, the excess being cut off with a heated putty knife.

After the cover is sealed in the connectors are soldered into place or bolted on, depending upon what type is used, and the battery is ready for service.

OPERATION

General Rules: In order that the best life may be obtained from a battery it is necessary to exercise the greatest care in the daily operation of the same. The following rules should be carefully followed:

Give the battery the proper amount of charge.
Do not undercharge the battery.
Do not overcharge the battery excessively.
Do not discharge the battery beyond safe limits.
Do not allow the battery to remain discharged.
INVESTIGATE AS SOON AS THERE ARE ANY SYMPTOMS OF TROUBLE.

Pilot Cell Operation: In order to determine the state of charge and discharge of a battery, the pilot method of operation is most reliable, as it is not to any great extent dependent upon the condition of the battery and operating conditions.

The pilot method of operation consists in taking the specific gravity of one cell in the battery and comparing the reading obtained with previous readings, thus determining the state of charge and discharge and the condition of the battery. The cell of which the specific gravity is taken is called the pilot cell and should be properly marked for identification.

In case the batteries are operated, two halves in parallel, it is necessary to have one pilot cell in each half.

In the pilot cell, the level of the electrolyte should be maintained as nearly constant as possible by the frequent addition of distilled water, the water being added after the specific gravity readings have been taken, but before the charge is started.

At the time that the battery is given the reforming charge, the specific gravity of the pilot cell and the temperature of the electrolyte should be taken; likewise at the end of the reforming charge. This should be recorded on the outside of the pilot cell. This specific gravity reading is called the maximum gravity and is used as a standard for judging the state of the charge and discharge of the cells.

Upon the arrival of the car in the yards, the specific gravity of the pilot cell, together with the temperature of the electrolyte, should be taken and properly recorded. The specific gravity reading should be corrected to 70° F. This reading compared with the maximum gravity and with previous readings will give the condition of the battery, and the same can be taken care of according to the conditions of the service.

If the battery is used in connection with the axle or the head-end systems, the pilot cell reading will show whether the battery needs an extra charge at the terminal, and it will also show whether the regulator on the machine is set properly.

Before the car leaves the terminal a second pilot cell reading can be taken, serving as a check on the amount of charge given the battery. This reading should also be recorded.

Voltage Operation: In addition to the specific gravity of the pilot cell, the terminal voltage of the battery should

be taken with all the lamps burning, and after they have been burning for at least five minutes.

This voltage reading serves as a check on the gravity reading. If it is lower than should be expected from the gravity reading, the voltage of each individual cell should be taken in order to detect those that are low. If any of these are found, the cause of the trouble should be investigated and remedied immediately.

In operating the battery the voltage alone should preferably not be used as a guide, as it will vary with the temperature, the age of the battery and the amount of current flowing from the battery.

Charging: In regular service the current at the beginning of the charge should be double the eight-hour discharge rate of the battery. If, for any reason, it is not practical to use this rate, any rate between the starting rate and the finishing rates can be used. The charge should be continued at this rate until the voltage rises to 2.55 volts per cell at a normal temperature, the rate then being reduced to the finish rate. Continue the charge at the lower rate until the voltage has ceased to rise and has reached a maximum. This point is determined by taking one-half hour readings toward the end of the charge.

The maximum voltage is not a fixed quantity but will vary to a great extent with the temperature, the age of the battery and the charging current.

If the temperature of the battery at any time during the charge rises to 110° F., the charging rate should be reduced or the battery should be allowed to rest until cool.

Reforming Charge: Regular charging in service may not completely reduce the sulphate in the plates, and it is, therefore, necessary to give the battery a reforming charge at regular intervals, the object being to reduce all sulphate and to even up the cells. The best time to give the battery this charge is when it is removed from the car for inspection, as the specific gravity should be used as a guide in bringing up the cells. Give the battery the regular service charge, then continue the charge at the finish rate until the gravity has ceased rising in every cell for at least one hour. If the battery is badly sulphated, this might take several days, in which case it will be necessary to take the battery out of service. Enough emphasis cannot be put on the necessity of doing this, as the life of the plates will be greatly shortened if the battery is allowed to continue in service in a sulphated condition.

At the end of the reforming charge, the voltage reading of each individual cell should be taken with the finish current flowing. This, together with the specific gravity reading of each cell, should be recorded.

Replacing Evaporation: Notwithstanding the fact that the cells are practically sealed, a certain amount of evaporation takes place. The evaporation is replaced at regular intervals with water, not acid, the object being to keep the plates always covered with electrolyte. The cells should be filled before charging. The water will then be properly mixed in the electrolyte by the gassing of the cell. In filling the cells the utmost care should be taken to see that the water is strictly pure. A convenient time for refilling the cells is when the battery is removed from the car for inspection and reforming charge. Batteries need filling oftener in summer than in winter, the amount of evaporation varying largely according to temperature.

Replacing Loss of Electrolyte: The proper height for the electrolyte is ¾ inch from the under side of the cover. It will be noticed that there is a slight and gradual loss of electrolyte. When this loss has become such that the highest reading that can be obtained is, say, 20 points below the standard (1220), or what it was when put into regular service, then the loss should be replaced by adding dilute acid. Before doing so, be sure the battery is completely charged and the specific gravity has remained constant for some time.

Concentrated acid should not be added to the electrolyte of a battery. An approximate density for this purpose is 1400 specific gravity. It is absolutely essential that pure acid be used. Commercial acid should not ordinarily be used unless it has been submitted to the battery company for a test and approval. Under ordinary circumstances it will not be found necessary to fill the cells with electrolyte between the cleanings. It is only in cases where slopping has taken place that this is necessary.

Batteries in Parallel: Charging batteries in parallel should be avoided, as different sets, as a rule, do not get equal loads, and after some time in service will become uneven. If the batteries are discharged in parallel it is advisable to charge them in series and always give the battery enough charge to bring up the lower set. If it is found necessary to charge the two sets in parallel, great care should be taken to see that both halves get the same amount of current and that both are brought up to normal. Parallel charging should not be used if there is any possible way by which it can be avoided.

Readings: For the proper operation of the battery the following readings should be taken and recorded:

Daily Readings Upon Arrival of Car in the Yard: Specific gravity of pilot cell.

Temperature of electrolyte in pilot cell.

Terminal voltage of battery with all lamps burning.

Daily Readings at End of Charge: Charging current and voltage every half hour toward the end of the charge.

Specific gravity of pilot cell.

Temperature of pilot cell.

Monthly Readings: Maximum gravity of pilot cell.

Specific gravity of each individual cell at the end of reforming charge.

Voltage reading of each individual cell at the end of the reforming charge with the current flowing.

Inspection: In order to get the best results from the battery it is essential that it be thoroughly inspected at least once a month. At the time of inspection the battery should also be given a reforming charge. The points to inspect and note are as follows:

The height of the electrolyte in the cell should be investigated as soon as the battery is removed from the car and, if necessary, the cells should be refilled with pure water to within ¾ inch below the inside of the cover before the battery is put on charge.

Inspect and clean all connectors and tighten them if necessary. Give all exposed metal parts on the connectors a coating of vaseline.

Inspect the gassing of the cells at the end of the charge. If any cell does not gas as freely as the balance the cause should be investigated.

Take the gravity readings of all the cells at the end of the charge.

Take the voltage readings of all the cells at the end of the charge with the charging current flowing. If any cells show low gravity or low voltage, the cause should be investigated.

Removal of Battery for Cleaning: In order to remove the sediment which accumulates in the bottom of the tank the battery should be removed from the car once a year for overhauling. This is preferably done when the car is being shopped for general repairs.

TAKING BATTERY OUT OF COMMISSION

If the battery is taken out of service for a short time it should be properly charged and stored away in a dry, cool place. It should be inspected at least once every month and refilled with water if necessary. At this time it should also be given a freshening charge at the finish rate.

If the battery is taken out of commission for more than six months the cells should be dismantled. Before doing this the battery should be fully charged and all the cells put into good condition. After dismantling, all the material except the groups should be thoroughly cleaned. The positive groups can be stored away and allowed to dry. The negative groups will heat as soon as they are exposed to the air. When they get warm they should be immersed in water until cooled off. They should then be allowed to dry, and if they again become heated they should be immersed in water a second time. They should again be allowed to dry, and can then be stored away.

When again put into service it should be treated as a new battery, as given under the heading, "Assembling and Initial Charge."

Battery boxes, battery tanks and connectors should be kept clean and dry. All parts liable to corrode should be painted with vaseline at regular intervals. Battery boxes and tanks should be painted with acid-proof paint every time the battery is removed for cleaning. Matches or exposed flames should not be allowed near the battery boxes, as the gases given off when the battery is charging are explosive.

TROUBLES AND THEIR REMEDIES

Indication of Troubles: The following symptoms indicate trouble in a cell and it is of the greatest importance to investigate the cause of the same and to remedy the trouble before it has injured the battery:

The cells show lack of capacity in service.

The voltage and specific gravity do not come up on charge.

The voltage and specific gravity are falling unusually low on discharge.

The cells are not gassing freely on charge.

Unusual heating on charge.

Color of plates is unhealthy.

Causes of Troubles: If a cell shows any of the above indications of trouble it can usually be traced to one of the following causes:

Impure electrolyte, the impurities having been introduced into the cell by using impure acid or water, or by allowing metal parts to enter into the cell.

Sulphate caused by the battery remaining in a discharged condition or being operated at high temperatures.

Short circuits caused by material lodging between the plates or sediment accumulating high enough to touch the bottom of the plates.

Positive plates worn out.

Negative plates low in capacity or worn out.

Remedies: If inspection of cells is properly followed out, and the troubles remedied as soon as found, the battery usually will give satisfactory service without great operation and maintenance cost or labor. If the battery is allowed to remain in service after showing indications of trouble the trouble will very soon develop seriously, and in time completely ruin the battery. A battery should, therefore, receive immediate attention when it shows that it is not operating along the regular lines.

Treatment of Cells With Impure Electrolyte: If the electrolyte is suspected to contain impurities, a one-quart bottle of the same should be sent immediately to a competent chemist to be analyzed.

If the electrolyte contains enough impurities to injure the plates it should be changed immediately. The battery should be discharged until the voltage of each cell reaches zero, the old electrolyte emptied out and the cells refilled with new electrolyte of the same density as the old. The battery should then be charged as stated under the heading, "Charging." If the cells contain a large amount of impurities it is advisable to repeat this operation two or three times. If the battery is allowed to continue in service when the electrolyte contains impurities, the plates will be injured, and in many cases completely ruined.

Treatment of Sulphated Cells: If a cell is allowed to sulphate to any extent the positive plates will corrode and deteriorate quickly. The remedy for sulphated cells is a complete charge until all the sulphate has been reduced. In case the whole battery is in a sulphated condition the charge should be started in the regular way, as given under the heading, "Charging," but in a case of this kind extreme care should be taken that the battery is not overheated. It is advisable in this case that the temperature does not exceed 100° F. In case this temperature is exceeded the charge should be discontinued until the battery has cooled down. The charge should then be continued at the finish rate until the gravity has reached a maximum and has remained at that point for at least six hours. If the cells are badly sulphated this may take several days.

If only one or two cells are found to be in a sulphated condition the simplest method of bringing them up is to charge the whole battery at the finish rate, until the gravity and the voltage have reached a maximum. If it is found that by this method the low cells cannot be brought up in a reasonable length of time, it is advisable to remove them from the car and replace them with fresh cells. The sulphated cells should then be charged separately until they are brought up, after which they should be put back in the car where they belong.

Treatment of Short-Circuited Cells: A short circuit usually starts from some small conducting particle lodging between the plates and will gradually develop if the particle is allowed to remain. The positive plates in the short-circuited cell will corrode quickly, and in a very short time will be absolutely destroyed. Short circuits should, therefore, be removed immediately. Short circuits from material lodging between the plates are not very liable to take place in serv-

ice, on account of the jarring and jolting of the train. If they occur, the cell should be completely dismantled, the short circuit removed, the separators replaced, and the cell again assembled. It should be filled with the old electrolyte or of new of the same density. It should then be thoroughly charged at the finish rate.

Cleaning: As stated under the heading "Removal of Battery for Cleaning," the battery should be cleaned once every year, or when the car is being shopped. Give the battery a thorough charge before cleaning.

The sealing compound, after being heated by a flame, is removed by a chisel or a screwdriver. Then remove the covers and lift the elements out from the tanks.

Remove the separators and rinse both the positive and negative groups and separators in running water. Great care should be taken to remove any loose particles which might cause a short circuit.

The old electrolyte is emptied from the tank, the sediment is removed, and the tank thoroughly rinsed with water. The element is then placed in the tank and the cell filled with new electrolyte of the same density as the electrolyte thrown away. The old solution should preferably be thrown away in order to get rid of possible impurities. The same operation is then performed with the next cell.

If the cells cannot be assembled immediately, the positive group can be left in the air, but the negative groups, as mentioned before, should be immersed in water or acid, preferably the latter. This will keep the negative plates in a charged condition and will decrease the amount of charge necessary after the cleaning is done. Any material, such as separators or rubber linings, found broken, should be replaced with new material.

After the whole battery has been assembled it should be put on charge as soon as possible and charged at the finish rate until the gravity ceases to rise.

The specific gravity in the various cells should be evened up, after which the battery is ready to be put back into service.

When the battery is being cleaned, the battery compartment in the car and the tanks should be thoroughly washed with a solution of bicarbonate of soda and, when dry, painted with acid-proof paint.

Test Discharge: Before the battery is put back into service it is advisable to give it a test discharge in order to determine whether it is still maintaining its capacity or is dropping behind.

The necessary instruments for running this test are an ammeter calibrated to 100 amperes, a low reading voltmeter, a hydrometer syringe, a thermometer and a rheostat. A water-rheostat is preferably used for this purpose, as it is very easily arranged and allows very close regulation of the circuit. It is made up of a crock or tub of about 10 or 15 gallons capacity and two lead or iron plates about 1 foot square and ¼ inch thick.

Connect one terminal of the battery to one of the plates of the rheostat, the other terminal to the ammeter and then to the second plate of the rheostat. Fill the crock with water and immerse the plates in the same. Pour a small quantity of sulphuric acid into the water until the desired current is obtained. Readings should be taken of the cell voltage every hour until the lowest cell has dropped to 1.8 volts, thus limiting the discharge and the capacity of the battery.

A convenient form of water-rheostat is a tub or crock filled with a very dilute solution of sulphuric acid or salt. One plate, mentioned above, is placed in the bottom of the tub while the other is suspended in the water from a pulley. The amount of current flowing can then be adjusted by the depth of suspension of this second plate.

The general practice in running a test as outlined above seems to be to take the terminal voltage of the whole battery instead of the voltage of individual cells and to discharge until a terminal voltage is reached equivalent to an average voltage per cell of 1.8 volts. This method will give the capacity of the battery under service conditions, but does not tell its actual condition, as there might be one or more cells considerably lower than the average, while the rest of them are above the average.

A battery with some high and some low cells is naturally not as good as one with all cells even, the average voltage for all being the same, as the low cells will continually be over-discharged and gradually ruined.

Cadmium Readings: If the entire battery is low in capacity, or if some low cells are found, it is necessary to know whether the trouble lies in the positive or negative plates. This can be determined by taking cadmium readings.

If a piece of metallic cadmium is immersed in the electrolyte directly above the plates, and is connected to the negative terminal of the voltmeter, while the positive terminal is connected to the positive pillar post by means of a pointed copper rod, a reading is obtained on the voltmeter.

The voltage between the positive post and the cadmium is approximately 2.20 volts at the beginning of the discharge. As the discharge is continued it gradually drops, and when it reaches 1.95 volts the positive plate is considered completely discharged.

The voltage between the negative post and the cadmium is approximately .14 volt at the beginning of the discharge. As the discharge is continued it gradually rises. The negative plate is considered completely discharged when the voltage has risen to .30.

In a new battery the negative plates are never completely discharged, as they have considerable excess capacity over the positive; therefore, the negative to cadmium reading in a new battery should not be higher than .20 at the end of discharge. It should be noted that the lower the reading obtained for the negative plates, the better the plates.

An example will show the use of cadmium readings in determining the condition of the plates. Assume that the voltage of a cell while being discharged at the eight-hour rate has dropped to 1.80 volts at the end of five hours, and that the cadmium reading for the positive plates is 1.95 volts and for the negative plates .15 volt. In this case the reading for the negative plates is considerably under the limit, while the positive plates are exhausted. This indicates either natural wear, or that all the sulphate has not yet been driven out from the plates. It is, therefore, advisable to take a second discharge. If the capacity is still the same, and too low for practical purposes, it will be necessary to renew the positive plates.

If the voltage of the cell is 1.80 at the end of five hours, and the cadmium reading for the positive plates is 2.12 volts, while for the negative plates it is .32 volt, this indicates that the positive plates are good and that the negative plates are short in capacity. In case the negative plates

are of the Planté type, this can be cured by rejuvenating (reversing).

Rejuvenating Negative Plates: The negative plates are so designed as to initially have an excess capacity, so that at the end of the life of the positive plates the negative plates will still give their rated capacity. If the cells have frequently been allowed to become sulphated, however, or if the electrolyte has been impure, the pores of the active material become clogged, causing a drop in capacity. It is advisable, therefore, to rejuvenate the negative plates whenever the positive plates are renewed, in order to obtain the most satisfactory results from the old negative groups during the life of the second set of positives. The rejuvenation in this case can be done with the old positive plates. Charge up the battery, and if any indications of short circuits are found, remove the same. Discharge the battery until the voltage of each cell reaches zero, and then charge in the reverse direction at two-thirds of the eight-hour rate until the gravity ceases to rise, which will probably take approximately 48 to 60 hours. Discharge the battery again, and then charge at two-thirds of the eight-hour rate in the right direction until the gravity again stops rising. The negative groups will then be ready to be assembled with new positives.

SECTION VI

MAZDA INCANDESCENT LAMPS

LIFE PERFORMANCE CURVES AND APPURTENANT DATA; LIGHT DISTRIBUTION CURVES. TRAIN LIGHTING AND REGULAR LAMPS

TRAIN LIGHTING LAMPS

Train lighting lamps used in good railway practice today resolve themselves substantially into one class, i.e., High Efficiency Mazda lamps. The Carbon, Gem and Tantalum fill so small a place in this field that their consideration is unnecessary.

At the present time the above lamps are listed in two voltages: 32 and 63 which have been adopted as standard by train lighting engineers throughout the country.

The general characteristics of these lamps are similar to those of the regular lamps of similar type used on standard commercial voltages such as 110 and 220 volts. Technical and other data relative to these types of train lighting lamps will be included according to the following outline:

Technical Data
Life Performance
Average Life Curves
Effect of Voltage Variation upon
- Candle-power
- Current
- Wattage

Candle-power Distribution Curves.

The Mazda lamp, as is well known, is an improved tungstent filament lamp having embodied in it the most recent science and developments in incandescent lamp manufacture. It has outclassed the other mentioned types of incandescent lamps due to its greater efficiency, its durability and the color quality of its light. These are the points of greatest moment, although it stands superior to the others in many other necessary qualifications.

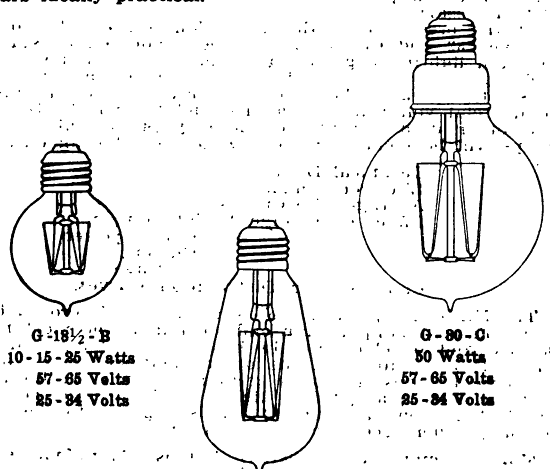
Mazda (Improved Tungsten) Lamps (Manufacture and Properties): The ingenuity of investigators was taxed to the extreme when Tungsten was first used as a lamp filament, as one of its characteristics was non-ductility or brittleness. Later is was discovered that with the proper treatment Tungsten became ductile and could be drawn into wire. Today it is being drawn into all sizes ranging in diameter from less than one-thousandth of an inch for the low current lamps up to one-hundredth of an inch for some types of series lamps. One-thousandth of an inch is smaller than the diameter of a hair. Tungsten wire is stronger than the strongest steel. The smaller sizes show a tensile strength of 600,000 pounds per square inch. While considerable of the strength is lost the first time the filament is heated to the working temperature, it is even then materially stronger than the filaments made by the squirting process. Also, the drawn filaments allow of a method of support which renders the lamps much more rugged. The spans are short and no welds are necessary.

The carbon filament incandescent train lighting lamp has been, up until approximately two years ago, in general use for this class of service since the introduction of railway electric lighting. Due to the fact that in practically all train lighting systems the lamps upon circuits are subject at regular or occasional intervals to much fluctuation in voltage, the carbon lamps of low efficiency were required.

The satisfactory operation of the electric lighting system with carbon filament lamps required large generator and battery equipment. The capacity, however, being somewhat limited by the available space on the car, with the larger cars, such as sleepers and diners, the allowable margin of safety was comparatively small, and resulted in numerous

lighting failures, which retarded considerably the universal adoption of electric lighting systems on steam roads.

The development of the high efficiency Mazda lamp which requires approximately but one-third the amount of current of the carbon filament lamp, has been the means of overcoming the foregoing trouble, making the electric lighting of cars ideally practical.



G-18½-B
10-15-25 Watts
57-65 Volts
25-34 Volts

S-19-C
10-15-20-25-40 Watts
(25-34) Volts
15-20-25-40 Watts
(57-65) Volts

G-30-C
50 Watts
57-65 Volts
25-34 Volts

Fig. 1. Mazda-Train Lighting Lamps

(Illustrations one-quarter size)

The most important item in the successful and economical operation of electric train lighting systems, is the efficiency of the lighting unit. Upon this depends directly the fixed charges and operating cost. From the hands of the electrical engineers as an experiment, the practical use of Mazda lamps has emanated as a necessary requirement. Their ruggedness in both the adopted standard voltages has been proven sufficient to withstand all reasonable shock and jar encountered in service. In candle-power maintenance through life, the following curves, Fig. 2, illustrate the superiority of the Mazda lamp. The decrease in efficiency is also much less than other incandescent lamps formerly used.

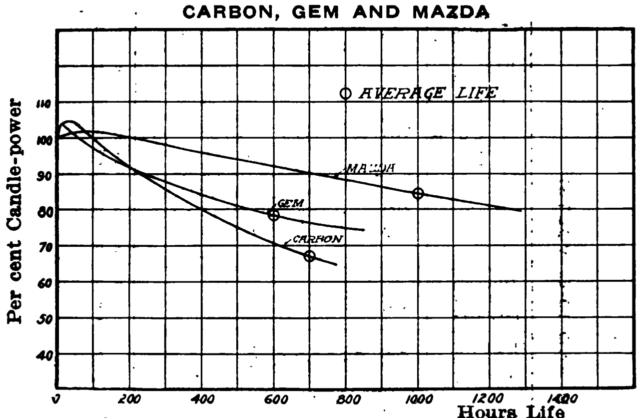


Fig. 2. Average Candlepower Life Curves

It is of interest to note the change in current, watts per candle and resistance through life as shown in Fig. 3.

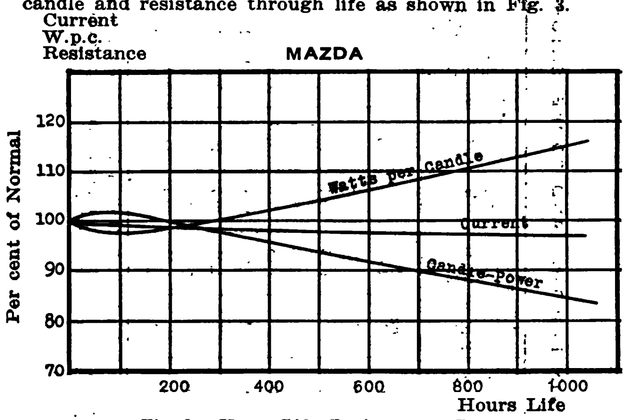


Fig. 3. Hours Life Performance Curves

At present train lighting lamps are made with two types of bulbs, the straight side and round. The first being divided in size into the S-17, S-19 and S-21, the second into G-18½ and G-30, having the wide range from 8 to 40 candle-power. There is little doubt but that the Mazda lamp has established electric train-lighting, and the increased economy coupled with its satisfaction as a lighting unit has begotten the endorsement of electric train-lighting engineers.

Regular Mazda Lamps: For standard multiple lighting of station train sheds, roundhouses, yards, etc., the Mazda lamp has also established itself as a successful and economical unit.

TRAIN LIGHTING AND COMPENSATOR (25-34 AND 50-65 VOLTS)

Class	Voltage Class	Rated Watts	Efficiency		Actual Watts	Mean Hor. Candle Power	% Spherical of Hor. Candle Power	Total Lumens	Lumens per Watt	Average Hours Total Life	Standard Package Quantity	Bulb		Length Over All Medium Screw Base, Ins.
			Rating	W. P. M. H. C. P.								Style	Diameter Inches	
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
GEM	57 to 65	20	Single	2.46	20.	8.1	84.5	86.4	4.32	300	200	G-12	1½	2⅛
	28 to 34	15	"	2.46	15.	6.1	84.5	64.8	4.32	300	200	G-12	1½	2⅛
"MAZDA"	57 to 65 25 to 34	10	"	1.23	9.8	8.0	79.0	79	8.07	1000	100	G-18½-B	2 5/16	3⅝
		15	"	1.23	14.8	12.0	79.0	119	8.07	1000	100	G-18½-B	2 5/16	3⅝
		20	"	1.23	19.7	16.0	79.0	159	8.07	1000	100	G-18½-B	2 5/16	3⅝
		25	"	1.23	24.6	20.0	79.0	199	8.07	1000	100	G-18½-B	2 5/16	3⅝
		50	"	1.23	49.2	40.0	79.0	397	8.07	1000	24	G-30-C	3¾	6⅛
	25 to 34 50 to 65	10	"	1.23	9.8	8.0	79.0	79	8.07	1000	100	S-17-B S-19-C	2⅛ 2⅜	4½ 5¼
		15	"	1.23	14.8	12.0	79.0	119	8.07	1000	100	S-17-B S-19-C	2⅛ 2⅜	4½ 5¼
		20	"	1.23	19.7	16.0	79.0	159	8.07	1000	100	S-17-B S-19-C	2⅛ 2⅜	4½ 5¼
		25	"	1.23	24.6	20.0	79.0	199	8.07	1000	100	S-17-B S-19-C	2⅛ 2⅜	4½ 5¼
		40	"	1.23	39.4	32.0	79.0	318	8.07	1000	100	S-19 C	2⅜	5¼
		50	"	1.23	49.2	40.0	79.0	397	8.07	1000	100	S-21-E	2⅝	5⅜

These lamps are regularly fitted with the Medium Screw base, except Gem, which is supplied with the Candelabra Screw base.

Round bulb Mazda train lighting lamps are regularly made with standard Medium Screw base but can be supplied in a longer base, which will allow their use in sockets with long husks.

MAZDA—STRAIGHT SIDE TYPE (100-130 VOLTS)

Voltage Class 1	Rated Watts 2	Efficiency: Rating 3	Efficiency: W. P. M. H. C. P. 4	Actual Watts 5	Mean Hor. Candle Power 6	% Spherical of Horizontal Candle Power 7	Total Lumens 8	Lumens Per Watt 9	Average Hours Total Life 10	Standard Package No. and Weight 11	Bulb, Style and Diameter 12	Length Over All Medium Screw Base 13
100 to 130		High	1.30	15.0	11.5		113	7.54	1000			
	15	Medium	1.36	14.6	10.8	78.0	105	7.21	1300	100	S-17-B 2⅛"	4½"
		Low	1.42	14.2	10.0		98	6.91	1700			
		High	1.25	20.0	16.0		157	7.84	1000			
	20	Medium	1.30	19.4	15.0	78.0	146	7.54	1300	100	S-17-B 2⅛"	4½"
		Low	1.35	18.8	14.0		137	7.26	1700			
		High	1.17	25.0	21.4		210	8.38	1000			
	25	Medium	1.22	24.3	20.0	78.0	195	8.04	1300	100 45 lb.	S-19-C 2⅜"	5¼"
		Low	1.27	23.6	18.6		182	7.72	1700			
		High	1.17	40.0	34.2		336	8.38	1000			
	40‖	Medium	1.22	38.9	33.0	78.0	313	8.04	1300	100† 60 lb.	S-21-E 2⅝"	5⅜"
		Low	1.27	37.8	29.8		292	7.72	1700			
		High	1.16	60.0	51.7		507	8.45	1000			
	60	Medium	1.21	58.3	48.4	78.0	473	8.10	1300	50 50 lb.	S-24½-A 3$\frac{1}{16}$"	7⅛"
		Low	1.26	56.6	45.1		441	7.78	1700			
		High	1.13	100.0	88.5		868	8.68	1000			
	100	Medium	1.18	97.2	82.8	78.0	808	8.31	1300	24 32 lb.	S-30-A 3¾"	7⅝"
		Low	1.23	94.4	77.1		753	7.97	1700			
		High	1.12	150.0	134.0		1312	8.76	1000			
	150	Medium	1.17	146.0	125.0	78.0	1223	8.38	1300	24 33 lb.	S-35-A 4⅜"	8¾"
		Low	1.22	142.0	116.0		1140	8.04	1700			
		High	1.00	250.0	250.0		2450	9.80	1000			
	250	Medium	1.04	243.0	234.0	78.0	2295	9.43	1300	12 27 lb.	S-40-B 5"	9¾"
		Low	1.08	236.0	218.9		2140	9.08	1700			

Specify clearly when lamps are ordered frosted, whether they are to be entirely frosted or bowl frosted. For illustration of bulbs, see opposite side of sheet. The Lamp Works will always ship high efficiency lamps where the Sales members specify only one voltage on their orders. ‖ Unskirted medium screw base; if skirted base, 6¼" long. † The 40 watt skirted base lamp when ordered in quantities of 100 can be shipped in two packages of 50 each.

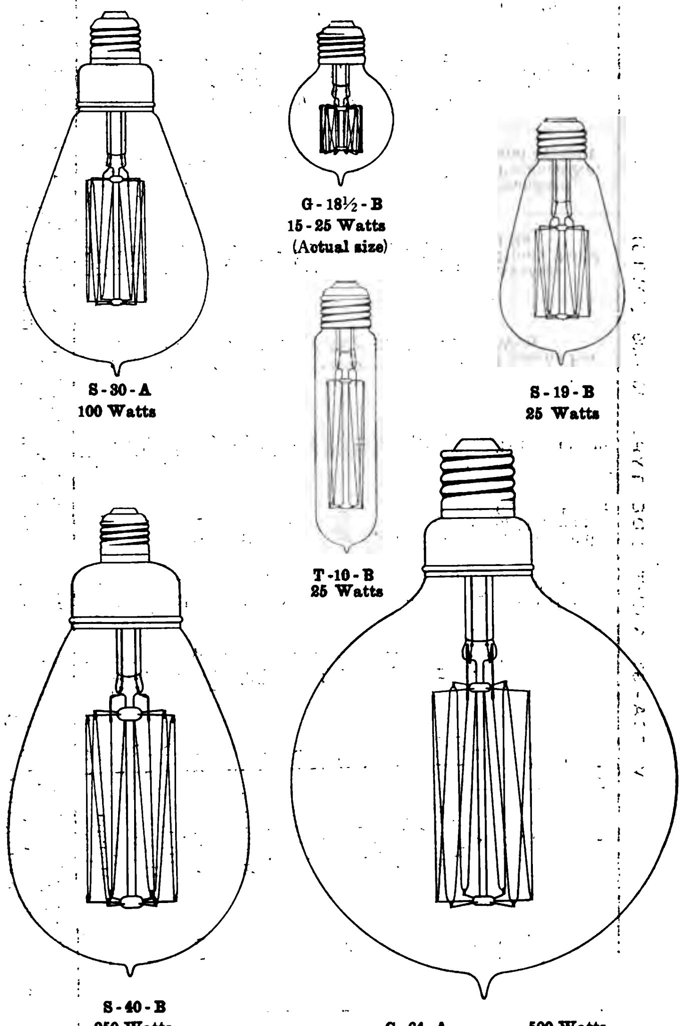
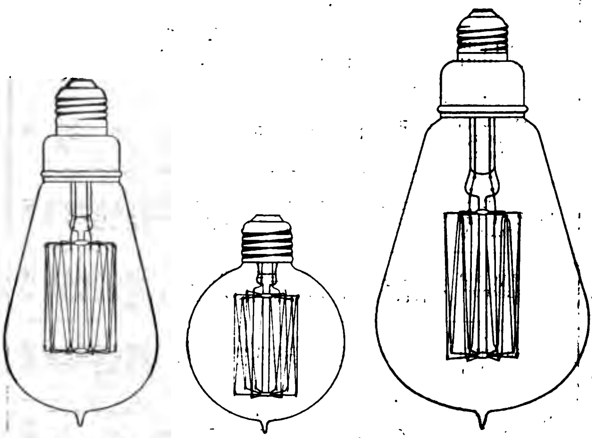


Fig. 4. "MAZDA" REGULAR LAMPS—100-130 VOLTS
One-quarter actual size

MAZDA—ROUND BULB, TUBULAR AND CONCENTRATED FILAMENT TYPES (100-130 VOLTS)

Voltage Class	Rated Watts	Efficiency: Rating	Efficiency: W. P. M. H. C. P.	Actual Watts	Mean Hor. Candle Power	% Spherical of Horizontal Candle Power	Total Lumens	Lumens Per Watt	Average Hours Total Life	Standard Package Quantity	Bulb, Style and Diameter	Length Over All Screw Base
1	2	4	5	6	7	8	9	10	11	12	13	14
100 to 130	15	High	1.30	15.0	11.5	78	113	7.54	500	100	G-18½-B 2⅜"	3⅝"
		Medium	1.36	14.6	10.8		105	7.21	650			
		Low	1.42	14.2	10.0		98	6.91	850			
	25*	High	1.17	25.0	21.4	78	210	8.38	1000	50	G-25-C 3⅛"	4⅝"
		Medium	1.22	24.3	20.0		196	8.04	1300			
		Low	1.27	23.6	18.6		182	7.72	1700			
	40	High	1.17	40.0	34.2	78	336	8.38	1000	50	G-25-C 3⅛"	4⅝"
		Medium	1.22	38.9	32.0		312	8.04	1300			
		Low	1.27	37.8	29.8		292	7.72	1700			
	60	High	1.16	60.0	51.7	78	507	8.45	1000	24	G-30-C 3¾"	5¼"
		Medium	1.21	58.3	48.4		473	8.10	1300			
		Low	1.26	56.6	45.1		441	7.78	1700			
	100	High	1.13	100.0	88.5	79	879	8.79	1000	24	G-35-A 4⅜"	7"
		Medium	1.18	97.2	82.8		820	8.42	1300			
		Low	1.23	94.4	77.1		762	8.07	1700			
	¶400	High	1.00	400.0	400.0	81	4070	10.18	1000	8	G-56-A 7"	10¾"
		Medium	1.04	389.0	375.0		3800	9.78	1300			
		Low	1.08	378.0	350.0		3565	9.43	1700			
	¶500	High	1.00	500.0	500.0	81	5089	10.18	1000	8	G-64-A 8"	11¾"
		Medium	1.04	486.2	467.5		4759	9.78	1300			
		Low	1.08	472.5	437.5		4453	9.43	1700			
	25	High	1.17	25.0	21.4	78	210	8.38	500	100 39 lbs.	T-10-B 1¼"	5¾"
		Medium	1.22	24.3	20.0		196	8.04	650			
		Low	1.27	23.6	18.6		182	7.72	850			
	†100	Single	1.23	100.0	81.3	95.5	976	9.76	250	24	G-30-A 3¾"	5¼"

¶ Skirted Mogul Screw Base. Orders should specify whether "bowl" frosted, "full" frosted, or plain lamps are desired.
† Concentrated Filament. * Can be supplied in G-18½-B bulb but it is not recommended.



S-24½-B
60 Watts

G-25-C
25 Watts

S-35-A
150 Watts

Fig. 5. 200-260 VOLT CLASS
One-quarter actual size

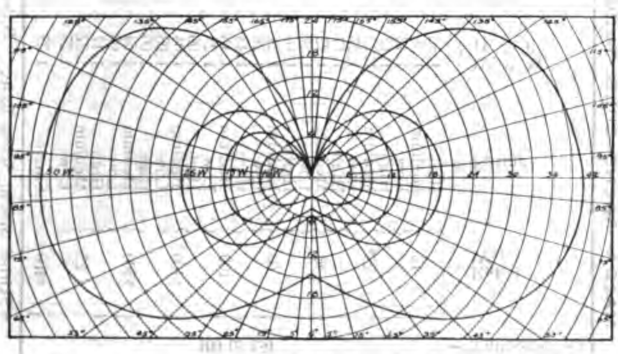


Fig. 6. Distribution Curves 10-15-25-50 Watt "Mazda" Train Lighting Lamps (25-34 Volt Class)

MAZDA—STRAIGHT SIDE (200-260 VOLTS)

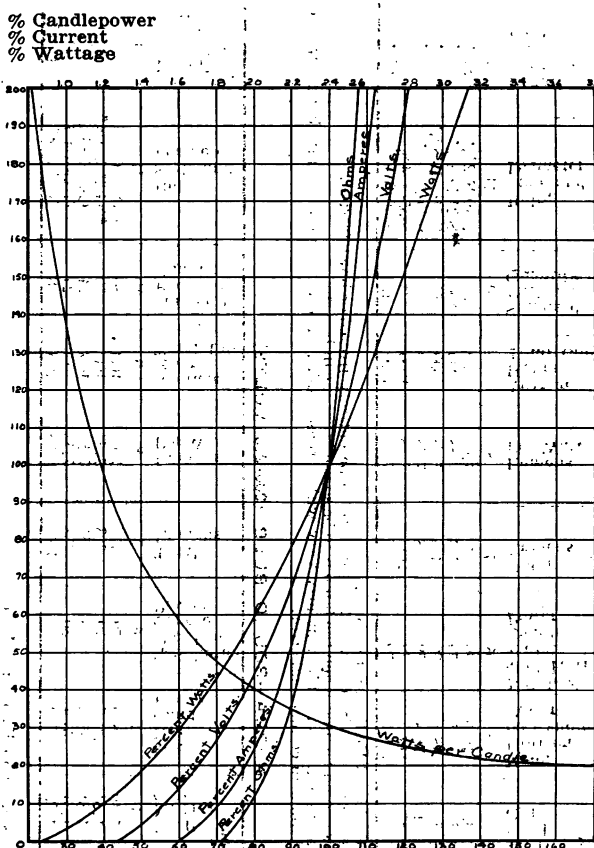
Voltage Class	Rated and Actual Watts	Efficiency		Mean Horizontal Candle Power	% Spherical of Horizontal Candle Power	Total Lumens	Lumens Per Watt	Average Hours Total Life	Standard Package Quantity	Bulb, Style and Diameter	Length Over All Screw Base
		Rating	W. P. M. H. C. P.								
1	2	3	4	5	6	7	8	9	10	11	12
200 to 260	25	Single	1.40	18.0	79	177	7.09	1000	100	S-19-F-2⅜"	5⅛"
	40	"	1.31	30.5	79	303	7.58	1000	100	**S-21-D-2⅝"	5½"
	60	"	1.31	45.8	79	455	7.58	1000	50	S-24½-B-3$\frac{1}{16}$"	7¼"
	100	"	1.31	76.4	79	758	7.58	1000	24	S-30-A-3¾"	7¾"
	150	"	1.31	114.5	79	1137	7.58	1000	24	S-35-A-4⅜"	8¾"
	250	"	1.31	191.0	79	1895	7.58	1000	12	S-40-B-5"	9¾"

** Regularly supplied with Unskirted Medium Screw Base.
Specify clearly, when lamps are ordered frosted, whether they are to be entirely frosted or bowl frosted.
Only frosted "Mazda" lamps should be used when the lamp is to be so used that it can be seen.
The wattage of individual lamps of any one shipment may vary within these limits. The c. p. will also vary, but the w. p. c. will be constant within the usual limits of commercial error.

MAZDA—ROUND BULB (200-260 VOLTS)

Voltage Class	Rated and Actual Watts	Efficiency		Mean Hor. Candle Power	% Spherical of Hor. Candle Power	Total Lumens	Lumens Per Watt	Average Hours Total Life	Standard Package Quantity	Bulb, Style and Diameter	Length Over All Screw Base
		Rating	W. P. M. H. C. P.								
1	2	3	4	5	6	7	8	9	10	11	12
200 to 260	25	Single	1.40	18.0	79	177	7.09	1000	50	**G-25-C-3⅛"	4⅝"
	40	"	1.31	30.5	79	303	7.58	1000	50	**G-25-C-3⅛"	4⅝"
	60	"	1.31	45.8	79	455	7.58	1000	24	G-30-C-3¾"	6¼"
	100	"	1.31	76.4	80	758	7.58	1000	24	G-35-A-4⅜"	7"
	*500	"	1.23	407.0	81	4140	8.28	1000	8	G-64-A-8"	11¾"

* Skirted Mogul Screw Base.
** Regularly supplied with Unskirted Medium Screw Base.
Specify clearly, when lamps are ordered frosted, whether they are to be entirely frosted or bowl frosted.



Percent Amperes, Ohms, Volts and Watts. Characteristic Curves for Mazda Drawn Wire Lamps

Fig. 7

The above figure may be of service in locating trouble since an idea may be obtained from it as to just what extent the voltage variation affects the other functions.

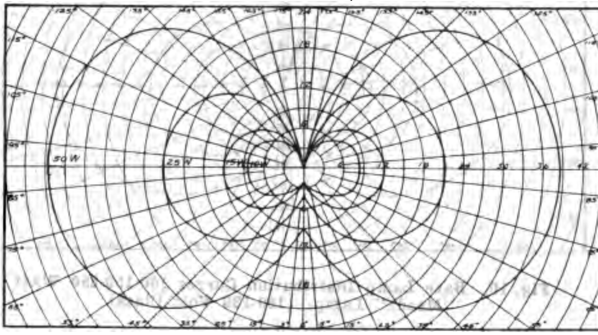


Fig. 8. Bare Lamp Distribution Curves 10-15-25-50 Watt "Mazda" Train Lighting Lamps (57-65 Volt Class)

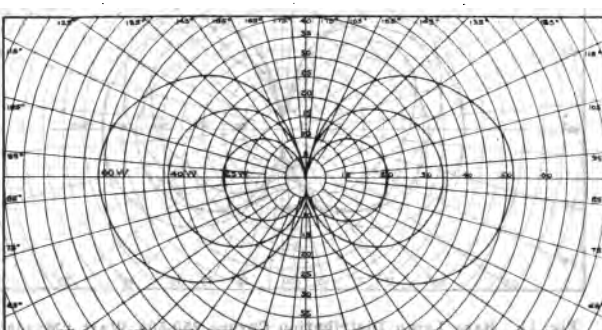


Fig. 9. Bare Lamp Distribution Curves 25-40-60 Watt "Mazda" Lamps (100-130 Volt Class)

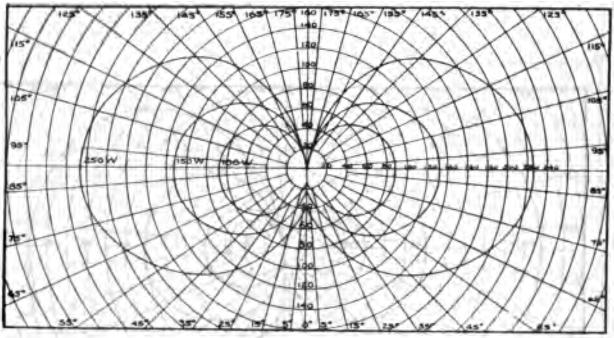


Fig. 10. Bare Lamp Distribution Curves 100-150-250 Watt "Mazda" Lamps (100-130 Volt Class)

The distribution curves given for the different wattage lamps of the 100-130 volt class are representative of that obtained from the 200-260 volt class which consequently have not been shown.

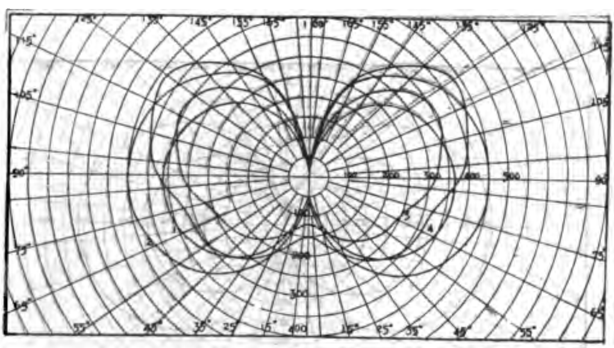


Fig. 11. Bare Lamp Distribution Curves 250-500 Watt "Mazda" Lamps (100-130 Volt Class)

The above illustrations show the distribution curves of the various lamps mentioned. These are known as bare lamp distribution curves which are modified greatly by the use of proper reflectors.

SECTION VII

LIGHT AND ILLUMINATION

INCLUDING LIGHT, PHOTOMETRY, ILLUMINATION AND APPURTENANT DATA

MEASUREMENT OF LIGHT

Rapid vibrations of the ether striking the retina of the eye produce a sensation commonly known as light. The intensity of light is measured in terms of candle-power on an instrument termed a photometer. In principle this instrument is based on the law of inverse squares, viz., that the intensity of light varies inversely with the square of the distance from the light source. Thus in Fig. 1, a surface C, twice the distance from A that B is, will be illuminated by the same number of light rays, but as the area is four times as great, the illumination will be only one-fourth that on B. Likewise, D, which is three times the distance and nine times the area of A, will have only one-ninth the illumination.

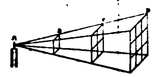


Fig. 1. Law of Inverse Squares Graphically

The Photometer: Photometry is a process of comparison. A standard light source whose candle-power has previously been determined is balanced against the light source of unknown candle-power by comparing the relative intensities produced on a sensitized screen. Generally the light sources are stationary 60" or 100" apart (thus designating the size of the photometer) and the screen movable. When a balance is secured the candle-powers of the two sources are in direct proportion to the squares of their respective distances from the screen. Accurate means of determining required voltage and current on standard and tested lamps is as necessary a requirement as a sensitive screen. This screen consists of a disk of white opaque material of high

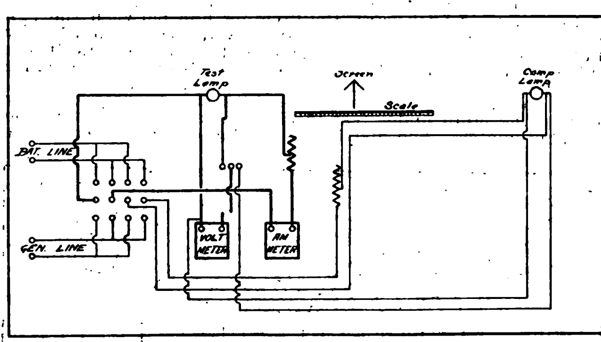


Fig. 2. Wiring Diagram of Modern Movable Screen Photometer

reflecting and diffusing power. Such screens are conveniently prepared by compressing into a circular hole in a metal plate either magnesium oxide, plaster paris or barium sulphate. An accumulation of dirt generally reduces the reflecting power of such screens and may render the two sides so dissimilar that a considerable change in the balance point is caused by a reversal of the screen.

In the plan view of Fig. 3, light from the lamps compared falls upon the sides of the diffusing screens S_1 and S_2. M_1 and M_2 are mirrors reflecting this light to prisms P_1 and P_2.

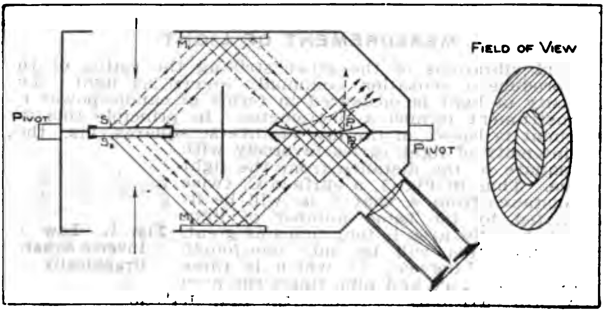


Fig. 3. Plan of Lummer Brodhun Sight Box

These prisms have their hypotenusal faces in contact in the central plane of the screen. Part of the face of P_1 is ground away leaving a circular area in contact with P_2. Of the light which enters P_1 from M_1 that which falls upon the area of contact passes through into the eyepiece and the remainder is turned aside by total reflection. P_2 reflects to the eyepiece the light which falls upon its outer portion, but that which meets the area of contact passes through and is absorbed in the blackened walls of the box. In the field of view the inner ellipse is thus illuminated by light from S_1 and the outer ellipse by light from S_2. If the face of P_1 is ground with care, the dividing line between the two ellipses may be made very sharp. With the field of view uniformly illuminated the boundary line disappears if the lights compared are of the same tint. If not, the balance must be obtained by the appearance of equal brightness.

The intensity in different directions can be measured by placing the lamp under test in different angular positions on the photometer. The distribution of light in a vertical plane

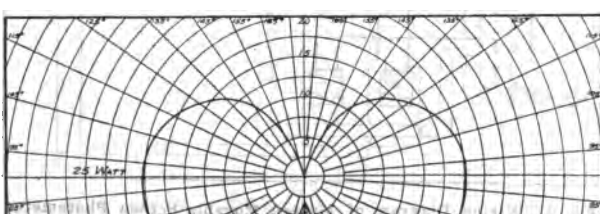


Fig. 4. Vertical Distribution 25-Watt MAZDA Lamp

can be graphically represented by plotting the results as shown in Fig. 4, which shows the distribution in a vertical plane about a bare 25-watt MAZDA lamp, hanging in a vertical position. The distance from the distribution curve to the center is directly proportional to the intensity of light in that direction, and this is indicated by the equally spaced concentric circles drawn on the figure.

When globes, shades or reflectors are used, as is generally the case, the distribution of light is materially modified, and, therefore, in order to make proper calculations, the photometric curves of the lamp with its reflector must be obtained.

Inasmuch as nearly one-half of the light from a bare lamp is thrown above the horizontal and largely lost, reflectors of various designs are used to direct the light where it is desired. Some of the vertical distribution curves, not only of the lamps themselves but also with reflectors of good design, are shown in this book.

ILLUMINATION

The term illumination may be defined as denoting the density of light flux falling upon a surface. The unit employed in America is the foot-candle denoting an illumination of one lumen per square foot, or further defined, represents the illumination received by a surface at every point one foot distant from a light source of one candle-power. Thus at point B in Fig. 5 an illumination of 1 ft. candle is received on the plane C, 1 ft. from the 1 candle-power, source A.

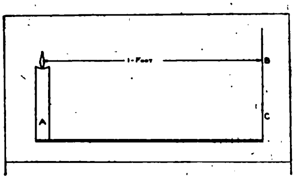


Fig. 5. Illumination is Likewise Measured by Comparison

Two standard portable photometers, known as the Weber and the Sharp-Millar, are excellent for making such measurements.

The Weber Photometer: Structurally considered, the Weber photometer consists of two cylindrical tubes of blackened interior as shown in Fig. 6, one of which, T, is firmly clamped to an upright standard and the other, T_2, is

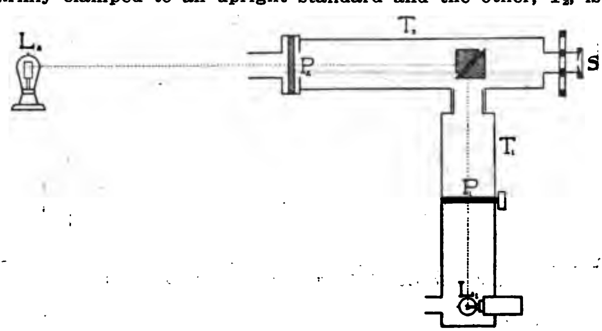


Fig. 6. Plan View of Weber Photometer

attached to one end of T_1 by a friction sleeve which permits T_2 to be turned to any desired angle in a vertical plane. The instrument as a whole may be turned to any desired angle about its standard as an axis, thus permitting the pointing of T_2 at any angle. Optically considered, the Weber instrument is a modification of the Lummer Brodhun photometer, the essential change being the substitution for the opaque screen of two glass diffusing plates, P_1 and P_2, placed between the prisms and the lamps to be compared. In a suitable chamber at the end of the lamp tube is mounted a comparison lamp L_1, preferably a miniature Mazda (Tungsten) lamp operated by a storage battery. This lamp should be well aged before use to insure its constancy.

The diffusing plate P_1 is movable along the axis of the tube by means of an external milled head carrying an index to indicate its position. At P_2 any one or more of a number of absorbing glass plates of different known transmission coefficients may be used interchangeably when needed in order to measure a high candle-power source.

Light from the test lamp L_2 falls upon the glass screen P_2 and light from the comparison lamps L_1 falls upon glass screen P_1 with a certain definite proportion of the light being transmitted in each case. By carefully adjusting the position of P_1 a balance between the two screens can be obtained when observed through the sight tube S.

A device is provided which can be attached at P_1 and which enables the observer to obtain the horizontal illumination with the tube T_2 in a horizontal position. This device is shown in Fig. 7, where R is a diffusing plate in a horizontal position and M is a mirror directing the light to P_2.

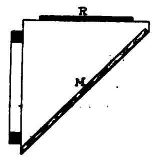


Fig. 7. Adapter for Illumination

***The Sharp-Millar Photometer:** This instrument is designed to apply the same principles upon which the Weber

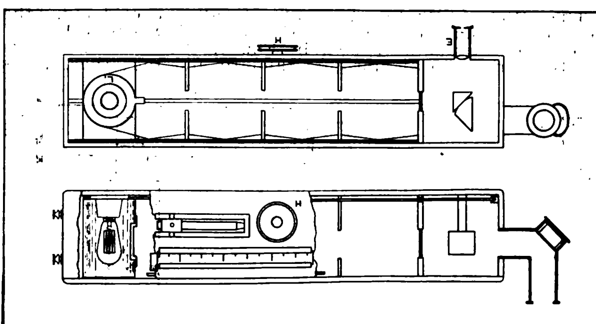


Fig. 8. Sectional View Sharp-Millar Photometer

photometer is constructed; however, a somewhat wider range of measurements is obtained. A compartment at one end of a box of blackened interior contains a Lummer Brodhun

*Note.—"Illumination and Photometry," Wickenden.

prism set, which may be observed through an eyepiece E on the side of the box. The adjacent end of the box carries a collar upon which an elbow T may be turned so as to expose its end at any desired inclination. Upon this end may be fitted a diffusing cap of special milk glass or an open diaphragm. At the elbow of the tube is a circular reversible plate, one side of which is a mirror for use with the diffusing test plate in the measurement of illumination. The other side is a white matte surface for use in connection with the diaphragm above referred to for measurements of candle-power. The end of the prism compartment opposite the elbow tube contains a milk glass window illuminated by the comparison lamp L_1 at the further end of the box.

This lamp is mounted upon a carriage which may be drawn along the interior of the box by turning the knurled head H. Between the lamp and the window is a series of screens to cut off from the window all but the direct beams of the lamp. The photometric balance is secured by drawing the comparison lamp along the interior of the box. When a balance is obtained the reading is taken by exposing a translucent scale on the side of the box by raising a shutter. This scale is made direct reading for comparing lamps of definite candle-power.

For measurements of illumination the elbow tube is fitted with its diffusing cap and its mirrored elbow plate. If the illumination is moderate in intensity it may be read direct from the scale. If intense illumination is measured a smoked-glass absorbing plate is required between the elbow tube and the prisms to equalize the two fields and bring the balance point within the limits of the scale. The scale readings must then be multiplied by the reciprocal of the transmission coefficient of this plate. For measurements of weak illumination the absorbing plate is required between the milk-glass window and the prism, and the readings of the scale are multiplied by the transmission coefficient of this plate. The instrument is provided with two such plates, which are so mounted that either may be turned by a milled head to a position in front of the elbow tube or before the window, or may be turned entirely out of the path of the beams. Convenient values for the transmission coefficients of these plates are 0.01 and 0.10, respectively, giving the instrument a range of from 0.004 foot-candles to 2000 foot-candles.

GENERAL CONDITIONS

Before going into the calculation and method of illumination, a discussion of the general conditions surrounding good illumination will be given. In order to see clearly and easily without eye strain the following conditions must prevail:

(1) There should be sufficient illumination, i. e., enough light must be reflected from the object to the eye so that it can be clearly and easily seen. For example, much more light must be thrown on a dark object than on a light one in order to see it clearly, since less light is reflected from a dark object than from a light one. Too little light should be avoided, as the retina is strained in its effort to see clearly. This is a matter of common knowledge and experience.

(2) Too much light should likewise be avoided. The condition produced by this is somewhat the same as that produced by too little light. To shield the excess light from the eye the iris naturally closes and with too intense

a light it closes to such an extent that the image on the retina is dim. If this condition continues for some time the iris weakens, thereby allowing the strong light to enter the eye. The strong light dims the image on the retina and at the same time produces a very harmful strain.

(3) Bright lights in the field of vision should be avoided as a picture of the light itself will be found on the retina and other objects will in comparison seem dim. This is the reason one is not able to see past a bright light and why a bright light is so dazzling in its effect. Therefore it is required that the intrinsic brilliancy or the candle-power per square inch of surface be as low as possible. The eye ordinarily can stand without fatigue a brilliancy of from

TABLE No. 1

Intrinsic Brilliancy of Light Sources

	Candle-power Per sq. in.
Moore tube	0.3– 1.75
Frosted incandescent	2– 5
Candle	3– 4
Gas flame	3– 8
Oil lamp	3– 8
Cooper Hewitt lamp	17
Welsbach gas mantle	20– 50
Acetylene	75–100
Enclosed A. C.	75–200
Enclosed D. C.	100–500
Incandescent lamps—	
Carbon 3.5 watts per candle	375
Carbon 3.1 watts per candle	480
Metallized carbon 2.5 watts per candle	625
Tantalum 2.0 watts per candle	750
MAZDA 1.25 watts per candle	875
MAZDA 1.15 watts per candle	1000
Nernst 1.5 watts per candle	2200
Sun on horizon	2000
Flaming arc	5000
Open arc lamp	10,000–50,000
Open arc crater	200,000
Sun 30° above horizon	500,000
Sun at zenith	600,000

four to six candle-power per square inch of surface. Table No. 1 shows the intrinsic brilliancy of several sources of light from which it will be noted that the incandescent lamp filament has an intrinsic brilliancy of from 300 to 1000 candle-power per square inch. For this reason frosted bulbs are often used, as the whole surface of the bulb is made the light emitting area instead of the filament area.

(4) Flickering sources of light are hard on the eye for the reason that the iris and retina of the eye are unable to adjust themselves with sufficient rapidity to follow the varying light intensity. Therefore, lamps should not be placed on circuits where the voltage fluctuates, as the candle-power of the lamps will vary with the rise or fall in voltage impressed upon the lamps.

(5) Lamps should be placed so that the light falling on a glazed or polished surface is not regularly reflected to the eye. This direct reflection is commonly known as glare, which besides being very annoying renders almost futile the effort to see clearly.

(6) Sources of light which cast streaks or striations are bad because the source frequently vibrates and the eye is unable to adjust itself to the different intensities produced. Thus in the case of lights covered by reflectors with a polished white interior surface frosted lamps should invariably be used.

(7) A sharp contrast between a light surface and dark surroundings is harmful, such as a brilliantly lighted desk with the rest of the room in darkness. A slight contrast is restful while a sharp contrast should be avoided.

Quality of Light: The "quality of light" of the MAZDA lamp is a subject upon which there has been considerable discussion. Results show that color comparisons can be made with the light of MAZDA lamps which compare very favorably with actual daylight. In comparing the effects of the color of various artificial sources of light and the change in the appearance of colored objects when illuminated by them, it has been conclusively shown that if there is a proper proportion of the red, green and blue fundamental colors in any given light source, all colors with their various shades of color can be accurately distinguished. The MAZDA lamp is a complete success from this standpoint. The proportions of the fundamental colors (red, green and blue) are such that colors and shades of colors appear in their proper relationship with each other.

TABLE No. 2

Illuminant	Color
Acetylene	Nearly white
Arc Light (enclosed)	Bluish white to violet
Arc Light (open)	White
Candle	Orange yellow
Carbon Incandescent (below voltage)	Orange to orange red
Carbon Incandescent (normal voltage)	Yellowish white
Gas Light (open flame)	Yellowish white to pale orange
Gem Metallized Filament Lamps	Nearly white, slightly yellowish
Kerosene Lamp	Orange, slightly yellowish
Nernst Lamp	Nearly white
Mantle Burner	Greenish white
Sky Light	Bluish white
Sun (high in sky)	White
Sun (near horizon)	Orange red
Tantalum	Nearly white
"MAZDA"	Nearly white

The MAZDA lamp is now developed to cover all general and special lighting service. It has been generally adopted and recommended from a practical and economical standpoint where a white light is desired for displaying colors in their true value.

TABLE No. 3

Color Values in Comparison With "MAZDA" Light

	Red	Green	Blue
MAZDA	100	100	100
Tantalum	100	96.8	73.6
Gem	100	92.6	72.8
Carbon	100	90.6	70.2

TABLE 4

Effect of Colored Lights on Various Colors from Dr. Bell's "Art of Illumination"

	Color of Light Falling Upon Fabrics					
Original Color of Fabric	Red	Orange	Yellow	Green	Blue	Violet
Black	Purplish-Black	Deep Maroon	Yellow-Olive	Greenish-Brown	Blue Black	Faint Violet Black
White	Red	Orange	Light Yellow	Green	Blue	Violet
Red	Intense Red	Scarlet	Orange	Brown	Violet	Red-Violet Purple
Orange	Orange Red	Intense Orange	Yellow-Orange	Faint Yellow, slightly Greenish	Brown slightly Violet	Light Red
Yellow	Orange	Yellow-Orange	Orange-Yellow	Yellowish-Green	Green	Brown tinged with Faint Red
Light Green	Reddish Gray	Yellow-Green	Greenish-Yellow	Intenser Green	Blue-Green	Light Purple
Deep Green	Reddish Black	Rusty Green	Yellowish Green	Intenser Green	Greenish Blue	
Light Blue	Violet	Orange-Gray	Yellowish-Green	Green-Blue	Vivid Blue	
Deep Blue		Gray slightly on Orange	Green-Slate	Blue-Green	Intenser Blue	Bright Blue-Violet
Indigo Blue		Orange-Maroon	Orange-Yellow (very dull)	Dull Green	Dark Blue-Indigo	Deep Blue-Violet
Violet	Purple	Red Maroon	Yellow-Maroon	Bluish Green-Brown	Deep Bluish Violet	Deep Violet

Reflection: The effect of the color of side walls and ceiling is one which must be considered in designing illumination. There is always some reflected illumination in a room and every object assumes that color due to the combination of the colors, the rays of which it reflects. An object appears light when it reflects those rays which make up white light and dark when it absorbs them: Thus light walls will give more useful reflected illumination than dark walls.

The following table gives approximate coefficients of reflection from wall papers, i. e., the amount of reflected light expressed as a proportion of the total light received by the surface, the figures being based on the use of incandescent lamps.

TABLE No. 5

Kind	Color	Coefficient of Reflection, K	$\frac{1}{1-K}$
Plain ceiling—	Faint greenish	.53	2.13
	Light yellow	.49	1.96
	Faint pinkish	.43	1.75
	Pale bluish white	.31	1.45
	Light gray green	.23	1.30
Crepe—	Medium green	.19	1.23
	Medium red	.08	1.09
	Deep green	.06	1.06
Cartridge—	Medium light buff	.44	1.79
	Light blue	.20	1.25
	Pale pink	.19	1.23
	Light green	.18	1.22
Striped— ("Two-toned")	Deep cream silvery	.57	2.32
	Light strawberry pink	.43	1.75
	Light green	.26	1.35
	Medium red	.08	1.09
Miscellaneous—	Light gray	.38	1.61
	Light green and gold (minute figuring, much gold)	.28	1.39

The following table is likewise included as it contains some very interesting data:

TABLE No. 6
Reflection Coefficients

White blotting paper	82
White cartridge paper	80
Ordinary foolscap	70
Ordinary newspaper	50 to 70
Chrome yellow paper	62
Orange paper	50
Plain boards (clean)	45
Yellow wall paper	40
Yellow painted wall (clean)	40
Light pink paper	36
Tracing cloth	35
Blue paper	25
Tracing paper	22
Plain boards (dirty)	20
Yellow painted wall (dirty)	20
Emerald green	18
Dark brown paper	13
Vermilion paper	12
Blue green paper	12
Cobalt blue paper	12
French ultramarine blue paper	3.5
Black cloth	1.2
Black paper	0.5
Deep chocolate paper	0.4
Black velvet	0.4

For Practical Problems the increase in illumination over that calculated from the distribution curve or illumination table for the unit considered is about as indicated in Table No. 6. These data are deduced from tests reported by Messrs. Lansingh and Rolph before the Illuminating Engineering Society.

This table applies only to rooms of medium size and average height of ceilings. The total amount of illumination or effective illumination in rooms of various colored walls is obtained by multiplying the illumination given directly by the lamp by the factor given in the last column, due to the fact that the bulbs of the lamps become dirty, thus lowering the candle-power while the walls become dirty, thus decreasing the amount of light reflected.

The amount of light absorbed by totally enclosing globes is an interesting matter as shown by the following table:

TABLE No. 7

Absorption Coefficients

Clear glass globes absorb from	5 to 12%
Light sand blasted globes absorb from	10 to 20%
Alabaster globes absorb from	10 to 20%
Canary-colored globes absorb from	15 to 20%
Light blue alabaster globes absorb from	15 to 25%
Heavy blue alabaster globes absorb from	15 to 30%
Ribbed glass globes absorb from	15 to 30%
Opaline glass globes absorb from	15 to 40%
Ground glass globes absorb from	20 to 30%
Medium opalescent globes absorb from	25 to 40%
Heavy opalescent globes absorb from	30 to 60%
Flame glass globes absorb from	30 to 60%
Signal green globes absorb from	80 to 90%
Ruby glass globes absorb from	85 to 90%
Cobalt blue globes absorb from	90 to 95%

METHODS OF ILLUMINATION

The proper lighting of a room depends on the style, character and desired effect. Common methods of lighting are by ceiling lights, stud or frieze lights, chandelier or wall bracket lights, indirect lights including cove and indirect reflectors.

Ceiling lighting requires lamps of high candle-power near the ceiling, with globes or reflectors to throw the light downward. In some cases a greater number of lamps of low candle-power are used in reflectors or in enclosing bowls. A reflector should be used inside the bowl.

Stud or frieze lighting requires that the sockets into which the lamps are screwed shall be imbedded in the ceiling or frieze. The lamps are seldom shaded and should be frosted if they are in the field of vision. An objection to this form of lighting is that it requires a large number of outlets and that unless some form of reflector is used it is inefficient and expensive to operate.

Chandeliers and wall brackets are often used for their decorative value. Various shapes and sizes of lamps are used on chandeliers and wall brackets so as to carry out and contribute to a desired decorative design. Except in cases where concentrating reflectors are required the lamps should not be placed at an angle, but should be hung vertically and either frosted or else covered with diffusing globes or shades, giving a wide distribution of light. Over

dining room tables, reading tables, etc., the lights should be placed vertically and equipped with concentrating reflectors.

Table or desk lights are employed for local illumination for reading, writing, or for attractive decorative effects in residence lighting. The lamps are usually clear, of medium candle-power and covered by some useful artistic shade.

Cove lighting requires lamps of medium candle-power concealed in troughs. The light is thus thrown directly on the ceiling and then diffused throughout the room. Cove lighting is not economical, since more than 50% of the light is lost by absorption.

Indirect lighting commonly known employs silvered reflectors inverted to throw the light toward the ceiling from which it is diffused and deflected. The scheme is likewise inefficient, though rendering effective a somewhat greater percentage of light than the cove system.

Basis of Illumination Calculation: As before given, the amount of light received by an object, per unit area, is measured in terms of foot-candles. This intensity varies inversely as the square of the distance of the light source from the plane when the ray strikes the plane normally as AB on CD in Fig. 9. If the surface is not normal to the rays as above the value of the illumination obtained as above must be multiplied by a correction factor dependent upon the angle at which the ray is incident. A beam of light coming in the direction AB falls upon the plane CD illuminating it to an intensity of 1 foot-candle. Thus the illumination on DE, which intercepts or receives the same light as AB, would be less than 1 foot-candle as the light is spread over a greater area. The ratio of the area would be as CD to DE, which represents the cosine of angle CDE. Thus the illumination effective on the plane at the given point will be

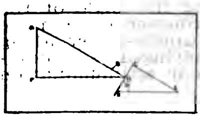


Fig. 9

$$I = \frac{CP}{\overline{AB}^{2}} \times \cos\theta$$

When θ is the angle between the direction of the ray and a perpendicular AF to the plane

$$AF = AB\cos\theta$$

$$AB = \frac{AF}{\cos\theta} \text{ and } \overline{AB}^{2} = \left(\frac{AF}{\cos\theta}\right)^{2}$$

$$I = \frac{CP}{\frac{AF^{2}}{\cos^{2}\theta}} \times \cos\theta \quad \text{or} \quad \frac{CP}{AF^{2}} \times \cos^{3}\theta$$

AF is the height of lamp above plane and if designated by H the general formula is obtained for any point.

$$I = \frac{CP}{H^{2}} \times \cos^{3}\theta = CP \times \frac{\cos^{3}\theta}{H^{2}}$$

As this computation for each point is extremely tedious the Table 8 has been computed for a one candle-power source in all directions. The constant computed in each rectangle representing

$$\frac{\cos^3\theta}{H^2}$$

for each foot out and down to the limit of 54 and 48 ft.

The basis of calculation on this method is the distribution curve of the lighting unit, which includes the reflector or globe. To find the illumination at any point the constant is found in the rectangle with the angle of the light ray to the chosen point. If the value of the candle-power of the source at this angle is multiplied by the constant the value of illumination is obtained.

Example

The illumination at a point 6 ft. out and 11 ft. down from a light source of 100-watts (Mazda) equipped with a metal reflector is desired. On the table accompanying, trace out to 6 ft., then down to 11 ft., where the constant .00590 is found with the angle 28° 37′ indicating the angle of the light ray to the chosen point. The distribution curve page 306 represents the light unit given; the candle-power along the angle 29° is found, as 155. Multiplying this candle-power, 155, by the constant .00559 results in an illumination of .866 foot-candle at the chosen point.

FEET	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
4	0°0' .062500	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	0°0' .040000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
6	0°0' .027780	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
7	0°0' .020410	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
8	0°0' .015630	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
9	[illegible] .012350	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
10	0°0' .010000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
11	0°0' .008260	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
12	0°0' .006940	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
13	0°0' .005920	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
14	0°0' .005100	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
15	0°0' .004440	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
16	0°0' .003910	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
17	0°0' .003460	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
18	0°0' .003090	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
19	0°0' .002770	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
20	0°0' .002500	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
21	0°0' .002267	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
22	0°0' .002066	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
23	0°0' .001890	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
24	0°0' .001736	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
25	0°0' .001600	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Table No. 8

Limits 18 Feet Out 25 Feet Down

FEET	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
26	0°0' .001480	2°12' .001470	4°23' .001466	6°33' .001410	8°42' .001438	10°25' .001401	13°0' .001369	14°46' .001331	17°3' .001290	19°5' .001248	21°5' .001200	23°26' .001156	24°46' .001108	26°34' .001058	28°30' .001008	29°59' .000961	31°35' .000916	33°11' .000867	34°42' .000821
27	0°0' .001372	2°7' .001370	4°14' .001360	6°20' .001345	8°25' .001327	10°30' .001303	12°32' .001275	14°32' .001243	16°30' .001208	18°26' .001170	20°20' .001130	22°11' .001088	23°58' .001046	25°43' .001002	27°25' .000959	29°4' .000916	30°40' .000874	32°12' .000831	33°41' .000790
28	0°0' .001276	2°3' .001270	4°5' .001265	6°7' .001253	8°8' .001235	10°7' .001216	12°5' .001190	14°2' .001164	16°0' .001132	17°49' .001100	19°40' .001062	21°28' .001027	23°10' .000991	24°55' .000952	26°34' .000911	28°11' .000874	29°44' .000834	31°17' .000797	32°44' .000758
29	0°0' .001189	1°59' .001185	3°57' .001180	5°54' .001170	7°51' .001155	9°47' .001137	11°41' .001116	13°34' .001091	15°25' .001064	17°20' .001033	19°8' .001004	20°47' .000974	22°29' .000938	24°9' .000903	25°47' .000869	27°21' .000833	28°52' .000798	30°23' .000763	31°56' .000727
30	0°0' .001111	1°54' .001109	3°50' .001105	5°43' .001093	7°35' .001080	9°28' .001065	11°20' .001041	13°8' .001025	14°55' .001002	16°42' .000977	18°25' .000947	20°9' .000920	21°50' .000889	23°26' .000858	25°0' .000826	26°34' .000791	28°3' .000765	29°33' .000734	31°0' .000700
31	0°0' .001040	1°51' .001039	3°41' .001036	5°32' .001025	7°21' .001015	9°10' .001001	10°57' .000985	12°43' .000966	14°28' .000946	16°11' .000924	17°53' .000897	19°33' .000871	21°10' .000843	22°46' .000816	24°19' .000788	25°49' .000758	27°18' .000730	28°44' .000701	30°9' .000673
32	0°0' .000976	1°48' .000974	3°35' .000970	5°22' .000964	7°7' .000952	8°53' .000942	10°37' .000927	12°21' .000910	14°2' .000892	15°42' .000872	17°22' .000849	18°59' .000826	20°33' .000802	22°7' .000777	23°39' .000752	25°7' .000726	26°34' .000699	28°0' .000673	29°22' .000646
33	0°0' .000919	1°44' .000918	3°28' .000914	5°12' .000908	6°55' .000898	8°37' .000888	10°19' .000874	11°59' .000860	13°37' .000843	15°16' .000824	16°51' .000803	18°26' .000784	20°0' .000762	21°30' .000740	23°0' .000717	24°27' .000694	25°52' .000670	27°15' .000646	28°37' .000622
34	0°0' .000865	1°41' .000864	3°22' .000860	5°3' .000853	6°42' .000847	8°22' .000838	10°0' .000826	11°38' .000813	13°14' .000798	14°50' .000781	16°23' .000764	17°57' .000745	19°27' .000726	20°56' .000705	22°23' .000684	23°48' .000663	25°13' .000641	26°34' .000620	27°54' .000598
35	0°0' .000816	1°38' .000815	3°16' .000812	4°54' .000807	6°31' .000800	8°8' .000792	9°44' .000781	11°19' .000770	12°53' .000756	14°25' .000742	15°57' .000726	17°27' .000708	18°56' .000692	20°23' .000672	21°48' .000654	23°12' .000634	24°34' .000614	25°55' .000594	27°13' .000576
36	0°0' .000773	1°36' .000770	3°11' .000768	4°46' .000763	6°20' .000757	7°54' .000750	9°28' .000740	11°0' .000730	12°32' .000718	14°2' .000704	15°32' .000690	17°0' .000674	18°26' .000659	19°53' .000642	21°15' .000624	22°37' .000608	23°58' .000589	25°17' .000571	26°34' .000552
37	0°0' .000731	1°33' .000730	3°6' .000727	4°38' .000723	6°10' .000718	7°42' .000710	9°13' .000702	10°43' .000693	12°12' .000682	13°40' .000670	15°8' .000657	16°34' .000644	17°58' .000629	19°22' .000613	20°44' .000598	22°4' .000582	23°24' .000565	24°41' .000549	25°57' .000531
38	0°0' .000693	1°30' .000692	3°1' .000690	4°31' .000687	6°0' .000681	7°30' .000675	8°59' .000667	10°27' .000659	11°54' .000648	13°19' .000638	14°45' .000626	16°9' .000614	17°33' .000601	18°53' .000587	20°14' .000573	21°33' .000558	22°51' .000542	24°6' .000528	25°21' .000512
39	0°0' .000657	1°28' .000656	2°56' .000654	4°24' .000651	5°51' .000647	7°18' .000641	8°45' .000633	10°11' .000631	11°35' .000618	13°0' .000608	14°25' .000597	15°48' .000586	17°7' .000574	18°26' .000562	19°44' .000548	21°3' .000535	22°19' .000521	23°33' .000507	24°47' .000492
40	0°0' .000625	1°26' .000624	2°52' .000622	4°17' .000619	5°43' .000616	7°7' .000610	8°32' .000604	9°56' .000597	11°19' .000589	12°41' .000580	14°2' .000571	15°23' .000560	16°42' .000550	18°0' .000538	19°17' .000526	20°33' .000513	21°48' .000501	23°2' .000487	24°14' .000474
41	0°0' .000595	1°24' .000594	2°48' .000592	4°11' .000590	5°34' .000586	6°57' .000582	8°20' .000576	9°41' .000569	11°3' .000562	12°23' .000554	13°42' .000546	15°1' .000536	16°19' .000526	17°36' .000513	18°52' .000504	20°6' .000493	21°20' .000481	22°32' .000469	23°43' .000457
42	0°0' [illegible]	1°22' .000566	2°44' .000565	4°5' .000563	5°26' .000559	6°48' .000555	8°8' .000550	9°28' .000544	10°47' .000537	12°5' .000530	13°24' .000522	14°41' .000513	15°57' .000504	17°13' .000494	18°26' .000484	19°39' .000474	20°51' .000463	22°3' .000452	23°13' .000440
43	0°0' .000541	1°20' .000540	2°40' .000539	4°0' .000537	5°19' .000534	6°38' .000530	7°56' .000525	9°15' .000520	10°33' .000514	11°49' .000507	13°5' .000499	14°21' .000492	15°36' .000483	16°50' .000474	18°2' .000465	19°14' .000455	20°25' .000445	21°35' .000435	22°45' .000425
44	0°0' .000517	1°18' .000516	2°36' .000515	3°55' .000513	5°12' .000510	6°29' .000506	7°46' .000502	9°2' .000497	10°18' .000491	11°33' .000486	12°48' .000479	14°3' .000471	15°16' .000464	16°28' .000455	17°39' .000447	18°49' .000438	20°0' .000428	21°8' .000419	22°15' .000410
45	0°0' .000494	1°16' .000493	2°33' .000492	3°49' .000490	5°5' .000488	6°20' .000485	7°36' .000481	8°51' .000476	10°5' .000471	11°19' .000466	12°32' .000459	13°44' .000453	14°56' .000446	16°7' .000438	17°17' .000430	18°26' .000422	19°34' .000413	20°42' .000404	21°48' .000395
46	0°0' .000473	1°15' .000472	2°29' .000471	3°44' .000469	4°58' .000467	6°12' .000462	7°26' .000461	8°39' .000457	9°52' .000452	11°4' .000447	12°16' .000441	13°27' .000435	14°38' .000428	15°47' .000421	16°56' .000414	18°4' .000406	19°11' .000398	20°17' .000390	21°23' .000382
47	0°0' .000453	1°13' .000452	2°26' .000451	3°39' .000450	4°52' .000448	6°4' .000445	7°16' .000442	8°28' .000438	9°40' .000433	10°50' .000429	12°1' .000424	13°11' .000418	14°20' .000412	15°28' .000405	16°35' .000399	17°43' .000392	18°48' .000384	19°53' .000377	20°57' .000369
48	0°0' .000434	1°12' .000436	2°23' .000433	3°35' .000431	4°46' .000429	5°57' .000427	7°7' .000424	8°18' .000420	9°28' .000416	10°37' .000412	11°46' .000407	12°55' .000402	14°3' .000396	15°9' .000390	16°15' .000384	17°21' .000378	18°27' .000370	19°30' .000364	20°33' .000356

Table No. 8—Continued
Limits 18 Feet Out 48 Feet Down

FEET	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
6	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
8	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
9	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
10	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
11	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
12	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
13	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
14	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
15	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
16	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
17	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
18	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
19	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
20	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
21	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
22	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
23	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
24	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
25	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Table No. 8—Continued
Limits 36 Feet Out 25 Feet Down

FEET	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
26	36°10' .000778	37°32' .000736	38°56' .000696	40°14' .000658	41°30' .000622	42°42' .000587	43°53' .000554	45°0' .000523	46°5' .000494	47°7' .000467	48°5' .000441	49°4' .000416	50°0' .000395	50°54' .000371	51°46' .000351	52°36' .000331	53°23' .000314	54°9' .000296
27	35°9' .000750	36°33' .000712	37°53' .000674	39°11' .000639	40°26' .000605	41°38' .000573	42°48' .000542	43°55' .000513	45°0' .000485	46°4' .000458	47°3' .000434	48°1' .000410	48°53' .000391	49°50' .000368	50°42' .000348	51°32' .000329	52°21' .000311	53°7' .000298
28	34°10' .000722	35°31' .000686	36°53' .000653	38°10' .000620	39°25' .000588	40°37' .000558	41°46' .000529	42°53' .000501	43°58' .000475	45°0' .000451	46°0' .000427	46°58' .000406	47°56' .000386	48°48' .000364	49°43' .000344	50°31' .000328	51°20' .000311	52°7' .000296
29	33°15' .000695	34°36' .000663	35°55' .000631	37°10' .000611	38°26' .000573	39°36' .000544	40°46' .000516	41°52' .000491	42°57' .000465	43°59' .000443	45°0' .000421	45°57' .000400	46°54' .000379	47°48' .000360	48°42' .000342	49°32' .000325	50°20' .000309	51°8' .000294
30	32°21' .000670	33°40' .000640	34°59' .000611	36°15' .000582	37°29' .000555	38°40' .000529	39°48' .000503	40°55' .000479	41°59' .000456	43°3' .000433	44°2' .000413	45°0' .000393	45°56' .000374	46°51' .000364	47°44' .000339	48°34' .000322	49°24' .000306	50°12' .000291
31	31°31' .000645	32°50' .000618	34°7' .000591	35°23' .000564	36°34' .000540	37°47' .000514	38°56' .000491	40°0' .000468	41°5' .000446	42°7' .000425	43°5' .000406	44°3' .000387	45°0' .000368	45°54' .000351	46°47' .000335	47°37' .000320	48°28' .000304	49°16' .000289
32	30°42' .000620	31°58' .000596	33°17' .000571	34°30' .000547	35°41' .000524	36°52' .000501	38°0' .000478	39°5' .000457	40°9' .000436	41°11' .000417	42°11' .000397	43°9' .000379	44°6' .000362	45°0' .000345	45°53' .000329	46°43' .000315	47°33' .000301	48°22' .000287
33	29°57' .000598	31°15' .000575	32°29' .000552	33°42' .000529	34°52' .000508	36°1' .000486	37°8' .000466	38°13' .000446	39°13' .000426	40°18' .000408	41°18' .000390	42°17' .000374	43°13' .000356	44°7' .000340	45°0' .000324	45°51' .000310	46°40' .000297	47°29' .000284
34	29°12' .000576	30°28' .000555	31°43' .000533	32°55' .000512	34°5' .000492	35°14' .000472	36°20' .000453	37°25' .000434	38°28' .000416	39°29' .000398	40°29' .000381	41°26' .000365	42°22' .000349	43°16' .000334	44°9' .000320	45°0' .000306	45°50' .000293	46°39' .000280
35	28°30' .000558	29°45' .000535	30°58' .000512	32°8' .000496	33°18' .000477	34°26' .000458	35°32' .000440	36°37' .000423	37°39' .000406	38°40' .000389	39°38' .000373	40°36' .000357	41°33' .000343	42°27' .000328	43°19' .000315	44°11' .000301	45°0' .000289	45°49' .000276
36	27°50' .000534	29°4' .000515	30°16' .000498	31°27' .000479	32°35' .000461	33°43' .000444	34°48' .000427	35°51' .000411	36°52' .000396	37°52' .000380	38°51' .000365	39°48' .000350	40°44' .000336	41°40' .000322	42°31' .000309	43°23' .000296	44°12' .000285	45°0' .000273
37	27°11' .000514	28°24' .000498	29°35' .000479	30°45' .000464	31°53' .000447	32°58' .000432	34°2' .000416	35°6' .000400	36°8' .000385	37°7' .000371	38°7' .000356	39°3' .000342	39°58' .000328	40°52' .000316	41°45' .000303	42°36' .000291	43°24' .000280	44°13' .000269
38	26°34' .000496	27°46' .000480	28°56' .000465	30°3' .000450	31°11' .000434	32°17' .000419	33°20' .000404	34°24' .000389	35°24' .000375	36°23' .000361	37°21' .000348	38°17' .000335	39°12' .000323	40°6' .000310	40°58' .000298	41°49' .000287	42°39' .000276	43°27' .000265
39	25°59' .000478	27°9' .000463	28°19' .000449	29°25' .000435	30°32' .000420	31°36' .000406	32°41' .000393	33°42' .000379	34°42' .000365	35°41' .000352	36°39' .000340	37°35' .000327	38°29' .000315	39°22' .000304	40°14' .000293	41°5' .000287	41°55' .000271	42°43' .000261
40	25°25' .000461	26°34' .000447	27°42' .000434	28°49' .000421	29°54' .000407	30°58' .000394	32°0' .000381	33°2' .000368	34°1' .000356	34°59' .000344	35°56' .000332	36°52' .000320	37°47' .000309	38°40' .000298	39°31' .000287	40°22' .000277	41°11' .000266	41°59' .000257
41	24°52' .000444	26°1' .000431	27°8' .000419	28°13' .000407	29°17' .000395	30°21' .000382	31°23' .000370	32°24' .000358	33°22' .000347	34°20' .000331	35°17' .000324	36°12' .000313	37°5' .000302	37°57' .000292	38°50' .000281	39°41' .000271	40°30' .000262	41°17' .000252
42	24°21' .000429	25°29' .000417	26°34' .000406	27°39' .000394	28°42' .000383	29°45' .000371	30°46' .000360	31°46' .000349	32°44' .000338	33°42' .000326	34°37' .000316	35°33' .000305	36°26' .000295	37°19' .000285	38°10' .000276	39°0' .000266	39°50' .000257	40°37' .000248
43	23°51' .000414	24°58' .000403	26°2' .000392	27°7' .000382	28°9' .000371	29°9' .000361	30°12' .000349	31°10' .000339	32°6' .000329	33°5' .000318	34°1' .000308	34°56' .000298	35°47' .000289	36°41' .000279	37°30' .000270	38°19' .000261	39°9' .000252	39°56' .000244
44	23°22' .000400	24°27' .000390	25°31' .000380	26°34' .000369	27°34' .000360	28°35' .000350	29°34' .000340	30°32' .000329	31°31' .000320	32°28' .000310	33°23' .000300	34°15' .000291	35°11' .000282	36°2' .000273	36°53' .000265	37°43' .000256	38°29' .000248	39°17' .000239
45	22°54' .000386	23°58' .000377	25°2' .000367	26°3' .000358	27°5' .000348	28°5' .000339	29°3' .000330	30°0' .000321	30°57' .000311	31°54' .000302	32°49' .000293	33°42' .000284	34°34' .000276	35°26' .000267	36°16' .000259	37°4' .000251	37°53' .000243	38°40' .000235
46	22°27' .000373	23°31' .000365	24°33' .000356	25°33' .000347	26°34' .000338	27°32' .000330	28°30' .000321	29°28' .000312	30°25' .000304	31°18' .000295	32°15' .000286	33°6' .000278	33°59' .000270	34°50' .000262	35°35' .000254	36°27' .000246	37°14' .000239	38°2' .000231
47	22°1' .000361	23°4' .000353	24°5' .000345	25°4' .000337	26°4' .000328	27°4' .000320	28°1' .000313	28°56' .000304	29°54' .000296	30°47' .000287	31°40' .000279	32°32' .000271	33°25' .000263	34°15' .000256	35°4' .000249	35°54' .000241	36°41' .000234	37°27' .000227
48	21°36' .000349	22°39' .000341	23°39' .000334	24°37' .000326	25°36' .000318	26°34' .000311	27°31' .000303	28°27' .000295	29°21' .000288	30°15' .000280	31°8' .000272	32°0' .000264	32°52' .000257	33°41' .000250	34°30' .000243	35°18' .000236	36°7' .000229	36°52' .000222

Table No. 8—Continued
Limits 36 Feet Out 48 Feet Down

FEET	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54
4	83°50' .000078	83°59' .000072	84°9' .000066	84°17' .000062	84°26' .000057	84°34' .000053	84°41' .000050	84°48' .000047	84°55' .000044	85°2' .000041	85°8' .000038	85°14' .000036	85°20' .000034	85°26' .000032	85°31' .000030	85°36' .000028	85°41' .000027	85°46' .000025
5	82°18' .000096	82°30' .000089	82°43' .000082	82°55' .000077	83°3' .000071	83°14' .000066	83°21' .000062	83°31' .000058	83°40' .000054	83°48' .000050	83°56' .000047	84°3' .000045	84°10' .000042	84°17' .000040	84°24' .000037	84°30' .000035	84°37' .000033	84°43' .000031
6	80°47' .000114	81°2' .000105	81°15' .000098	81°28' .000091	81°40' .000085	81°52' .000079	82°3' .000074	82°14' .000069	82°24' .000064	82°34' .000060	82°43' .000057	82°52' .000053	83°1' .000050	83°8' .000047	83°17' .000045	83°25' .000042	83°31' .000040	83°40' .000037
7	79°17' .000131	79°36' .000121	79°49' .000113	80°5' .000106	80°18' .000098	80°32' .000091	80°45' .000085	80°58' .000079	81°10' .000074	81°21' .000069	81°32' .000065	81°42' .000061	81°52' .000058	82°2' .000054	82°11' .000051	82°20' .000049	82°29' .000046	82°37' .000043
8	77°48' .000147	78°7' .000137	78°25' .000127	78°41' .000118	78°58' .000110	79°13' .000103	79°28' .000095	79°41' .000089	79°55' .000084	80°8' .000079	80°20' .000074	80°32' .000070	80°44' .000065	80°55' .000062	81°5' .000058	81°15' .000055	81°25' .000052	81°34' .000049
9	76°21' .000162	76°41' .000151	77°0' .000141	77°19' .000131	77°37' .000122	77°54' .000114	78°10' .000107	78°26' .000099	78°41' .000093	78°55' .000087	79°9' .000082	79°23' .000077	79°36' .000073	79°48' .000069	80°0' .000065	80°11' .000061	80°21' .000058	80°32' .000055
10	74°53' .000177	75°15' .000165	75°37' .000153	75°58' .000143	76°18' .000133	76°37' .000125	76°56' .000116	77°13' .000109	77°30' .000102	77°46' .000096	77°59' .000090	78°16' .000085	78°30' .000080	78°44' .000076	78°56' .000071	79°7' .000067	79°19' .000064	79°31' .000060
11	73°27' .000191	73°51' .000178	74°15' .000165	74°38' .000154	74°59' .000144	75°20' .000134	75°40' .000126	75°58' .000118	76°16' .000111	76°33' .000104	76°50' .000098	77°6' .000092	77°21' .000087	77°36' .000082	77°50' .000077	78°3' .000073	78°17' .000069	78°30' .000065
12	72°1' .000204	72°28' .000190	72°54' .000177	73°18' .000165	73°42' .000154	74°5' .000144	74°26' .000135	74°46' .000126	75°6' .000119	75°23' .000112	75°41' .000105	75°58' .000099	76°14' .000094	76°30' .000088	76°46' .000083	77°0' .000079	77°15' .000075	77°28' .000071
13	70°39' .000215	71°8' .000200	71°34' .000187	72°0' .000174	72°25' .000163	72°48' .000153	73°11' .000143	73°33' .000134	73°53' .000126	74°14' .000119	74°33' .000113	74°51' .000106	75°9' .0000996	75°26' .000094	75°42' .000089	75°57' .000084	76°12' .000080	76°28' .000076
14	69°16' .000226	69°47' .000211	70°15' .000197	70°43' .000184	71°9' .000172	71°34' .000161	71°58' .000151	72°21' .000142	72°43' .000134	73°5' .000126	73°25' .000119	73°44' .000112	74°3' .000106	74°22' .0000999	74°39' .000094	74°57' .000089	75°13' .000085	75°28' .000081
15	67°56' .000236	68°26' .000221	68°57' .000206	69°27' .000192	69°53' .000181	70°21' .000169	70°46' .000159	71°11' .000149	71°34' .000141	71°56' .000133	72°18' .000125	72°39' .000118	72°59' .000111	73°18' .000106	73°37' .0000997	73°55' .000094	74°13' .000090	74°29' .000085
16	66°37' .000244	67°10' .000228	67°41' .000214	68°12' .000200	68°41' .000188	69°9' .000176	69°35' .000166	70°1' .000156	70°27' .000146	70°49' .000138	71°13' .000130	71°34' .000124	71°55' .000117	72°16' .000111	72°36' .000105	72°54' .000099	73°13' .000094	73°30' .000090
17	65°20' .000253	65°54' .000236	66°26' .000221	66°59' .000207	67°29' .000194	67°58' .000183	68°26' .000172	68°53' .000162	69°19' .000153	69°43' .000144	70°7' .000136	70°30' .000129	70°52' .000122	71°13' .000116	71°34' .000109	71°54' .000104	72°13' .000099	72°32' .000094
18	64°4' .000258	64°39' .000242	65°13' .000227	65°46' .000213	66°18' .000201	66°48' .000189	67°18' .000177	67°45' .000168	68°12' .000158	68°38' .000149	69°3' .000141	69°26' .000134	69°50' .000126	70°13' .000120	70°34' .000114	70°55' .000108	71°15' .000103	71°34' .000098
19	62°50' .000264	63°26' .000248	64°1' .000233	64°36' .000219	65°9' .000206	65°39' .000194	66°9' .000183	66°39' .000173	67°7' .000163	67°33' .000154	67°59' .000146	68°25' .000138	68°48' .000131	69°11' .000124	69°34' .000118	69°47' .000111	70°17' .000106	70°37' .000101
20	61°36' .000268	62°15' .000253	62°51' .000238	63°26' .000224	64°0' .000211	64°32' .000199	65°3' .000188	65°33' .000177	66°3' .000168	66°30' .000159	66°57' .000150	67°23' .000142	67°48' .000135	68°12' .000128	68°35' .000122	68°58' .000116	69°20' .000110	69°41' .000105
21	60°25' .000273	61°5' .000256	61°42' .000241	62°18' .000228	62°53' .000215	63°26' .000203	63°58' .000192	64°29' .000181	64°59' .000172	65°28' .000162	65°56' .000154	66°23' .000146	66°48' .000139	67°13' .000132	67°37' .000125	68°0' .000119	68°23' .000113	68°45' .000108
22	59°16' .000276	59°57' .000259	60°34' .000245	61°12' .000231	61°46' .000219	62°22' .000206	62°54' .000195	63°26' .000185	63°57' .000175	64°26' .000166	64°56' .000157	65°22' .000150	65°48' .000142	66°15' .000135	66°40' .000128	67°4' .000121	67°28' .000116	67°50' .000111
23	58°8' .000278	58°49' .000263	59°28' .000248	60°6' .000234	60°43' .000222	61°18' .000209	61°51' .000198	62°24' .000188	62°56' .000178	63°26' .000169	63°57' .000160	64°23' .000153	64°51' .000145	65°17' .000138	65°43' .000132	66°9' .000125	66°33' .000119	66°56' .000114
24	57°5' .000280	57°43' .000265	58°24' .000250	59°2' .000236	59°40' .000224	60°15' .000212	60°49' .000201	61°25' .000190	61°56' .000181	62°28' .000172	62°57' .000163	63°26' .000155	63°54' .000148	64°21' .000141	64°48' .000134	65°13' .000128	65°38' .000122	66°2' .000116
25	55°57' .000280	56°40' .000266	57°20' .000252	58°0' .000240	58°38' .000226	59°14' .000216	59°50' .000204	60°24' .000193	60°57' .000183	61°29' .000173	61°59' .000165	62°29' .000157	62°58' .000150	63°26' .000143	63°53' .000136	64°19' .000130	64°45' .000122	65°9' .000118

Table No. 8—Continued
Limits 54 Feet Out 25 Feet Down

FEET	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54
26	54°54′ .000281	55°38′ .000266	56°19′ .000253	56°59′ .000240	57°37′ .000228	58°14′ .000217	58°51′ .000206	59°25′ .000196	59°59′ .000186	60°31′ .000177	61°3′ .000169	61°33′ .000159	62°3′ .000152	62°32′ .000145	63°0′ .000138	63°26′ .000132	63°52′ .000126	64°17′ .000121
27	53°51′ .000280	54°36′ .000266	55°18′ .000253	55°59′ .000240	56°38′ .000228	57°16′ .000218	57°53′ .000207	58°28′ .000198	59°2′ .000187	59°36′ .000178	60°8′ .000170	60°39′ .000161	61°9′ .000154	61°38′ .000147	62°6′ .000141	62°34′ .000134	63°0′ .000128	63°26′ .000123
28	52°49′ .000285	53°37′ .000268	54°18′ .000253	55°1′ .000239	55°40′ .000228	56°19′ .000218	56°55′ .000208	57°31′ .000198	58°6′ .000189	58°40′ .000179	59°13′ .000171	59°44′ .000163	60°15′ .000156	60°44′ .000149	61°14′ .000142	61°42′ .000135	62°9′ .000130	62°35′ .000124
29	51°48′ .000279	52°40′ .000265	53°23′ .000252	54°3′ .000240	54°44′ .000229	55°23′ .000218	55°59′ .000208	56°36′ .000199	57°11′ .000190	57°46′ .000181	58°19′ .000173	58°51′ .000165	59°22′ .000159	59°53′ .000151	60°23′ .000145	60°51′ .000137	61°19′ .000132	61°46′ .000126
30	50°53′ .000278	51°42′ .000265	52°26′ .000252	53°8′ .000240	53°48′ .000229	54°28′ .000218	55°6′ .000208	55°45′ .000198	56°19′ .000190	56°53′ .000181	57°27′ .000174	58°0′ .000167	58°31′ .000160	59°2′ .000152	59°32′ .000147	60°1′ .000139	60°28′ .000133	60°57′ .000127
31	50°2′ .000272	50°47′ .000263	51°33′ .000251	52°15′ .000239	52°56′ .000227	53°36′ .000217	54°13′ .000208	54°50′ .000198	55°24′ .000190	56°1′ .000182	56°35′ .000174	57°8′ .000167	57°40′ .000160	58°12′ .000154	58°42′ .000146	59°13′ .000141	59°40′ .000136	60°9′ .000129
32	49°8′ .000274	49°53′ .000261	50°37′ .000249	51°21′ .000238	52°1′ .000227	52°43′ .000217	53°20′ .000208	53°58′ .000198	54°35′ .000190	55°16′ .000182	55°46′ .000174	56°19′ .000167	56°51′ .000160	57°22′ .000154	57°54′ .000148	58°24′ .000141	58°52′ .000135	59°22′ .000130
33	48°16′ .000271	49°1′ .000259	49°45′ .000247	50°28′ .000237	51°10′ .000227	51°50′ .000217	52°28′ .000208	53°8′ .000199	53°45′ .000190	54°21′ .000182	54°55′ .000174	55°30′ .000167	56°3′ .000161	56°34′ .000154	57°5′ .000148	57°36′ .000142	58°5′ .000137	58°35′ .000131
34	47°25′ .000268	48°11′ .000256	48°54′ .000246	49°37′ .000235	50°19′ .000225	51°0′ .000216	51°40′ .000206	52°18′ .000198	52°55′ .000190	53°32′ .000182	54°6′ .000174	54°41′ .000167	55°14′ .000160	55°47′ .000154	56°19′ .000148	56°49′ .000142	57°19′ .000136	57°48′ .000131
35	46°36′ .000265	47°20′ .000254	48°4′ .000244	48°49′ .000233	49°30′ .000224	50°12′ .000214	50°51′ .000205	51°30′ .000197	52°8′ .000189	52°44′ .000181	53°19′ .000174	53°53′ .000167	54°28′ .000160	55°1′ .000154	55°32′ .000148	56°3′ .000142	56°33′ .000137	57°2′ .000132
36	45°47′ .000262	46°33′ .000251	47°17′ .000241	48°0′ .000231	48°44′ .000221	49°24′ .000213	50°3′ .000204	50°42′ .000196	51°20′ .000189	51°57′ .000181	52°33′ .000174	53°7′ .000167	53°42′ .000160	54°16′ .000154	54°47′ .000148	55°19′ .000142	55°45′ .000137	56°19′ .000132
37	45°0′ .000258	45°45′ .000248	46°30′ .000238	47°13′ .000229	47°56′ .000220	48°36′ .000211	49°17′ .000203	49°57′ .000195	50°34′ .000187	51°11′ .000180	51°47′ .000173	52°23′ .000166	52°56′ .000160	53°30′ .000154	54°3′ .000148	54°35′ .000142	55°5′ .000137	55°36′ .000132
38	44°14′ .000254	45°0′ .000245	45°44′ .000235	46°27′ .000226	47°10′ .000218	47°51′ .000209	48°30′ .000201	49°11′ .000193	49°49′ .000186	50°26′ .000179	51°3′ .000172	51°38′ .000166	52°13′ .000159	52°45′ .000154	53°19′ .000148	53°51′ .000142	54°22′ .000137	54°53′ .000132
39	43°30′ .000251	44°16′ .000241	45°0′ .000232	45°43′ .000224	46°26′ .000215	47°7′ .000207	47°46′ .000200	48°28′ .000192	49°6′ .000185	49°43′ .000178	50°19′ .000171	50°55′ .000165	51°30′ .000159	52°3′ .000153	52°36′ .000147	53°7′ .000142	53°40′ .000137	54°10′ .000132
40	42°46′ .000247	43°32′ .000238	44°17′ .000229	45°0′ .000221	45°42′ .000213	46°24′ .000205	47°4′ .000198	47°44′ .000190	48°22′ .000183	48°59′ .000177	49°36′ .000170	50°12′ .000164	50°46′ .000158	51°20′ .000152	51°54′ .000147	52°26′ .000142	52°58′ .000137	53°29′ .000132
41	42°5′ .000243	42°49′ .000235	43°35′ .000226	44°18′ .000218	45°0′ .000210	45°41′ .000203	46°22′ .000195	47°1′ .000189	47°40′ .000182	48°18′ .000175	48°55′ .000169	49°29′ .000163	50°5′ .000157	50°39′ .000152	51°12′ .000146	51°44′ .000141	52°17′ .000136	52°47′ .000132
42	41°23′ .000239	42°9′ .000231	42°53′ .000223	43°37′ .000215	44°19′ .000208	45°0′ .000201	45°40′ .000194	46°22′ .000186	46°59′ .000180	47°37′ .000174	48°14′ .000168	48°49′ .000162	49°24′ .000156	49°59′ .000151	50°32′ .000146	51°6′ .000140	51°37′ .000136	52°9′ .000131
43	40°42′ .000236	41°29′ .000227	42°13′ .000220	42°57′ .000212	43°39′ .000205	44°20′ .000198	45°0′ .000191	45°39′ .000185	46°19′ .000178	46°56′ .000172	47°33′ .000166	48°10′ .000160	48°45′ .000155	49°19′ .000150	49°52′ .000145	50°25′ .000140	50°57′ .000135	51°30′ .000131
44	40°4′ .000233	40°50′ .000224	41°33′ .000217	42°16′ .000209	43°0′ .000202	43°40′ .000196	44°20′ .000189	45°0′ .000183	45°38′ .000177	46°16′ .000171	46°55′ .000165	47°29′ .000159	48°5′ .000154	48°39′ .000149	49°14′ .000144	49°45′ .000139	50°19′ .000135	50°50′ .000130
45	39°26′ .000228	40°12′ .000220	40°55′ .000213	41°38′ .000206	42°21′ .000199	43°3′ .000193	43°41′ .000187	44°22′ .000181	45°0′ .000175	45°37′ .000169	46°15′ .000163	46°52′ .000157	47°27′ .000153	48°1′ .000148	48°36′ .000143	49°7′ .000139	49°46′ .000134	50°12′ .000130
46	38°49′ .000224	39°33′ .000217	40°17′ .000210	41°0′ .000203	41°42′ .000197	42°24′ .000190	43°4′ .000184	43°43′ .000179	44°23′ .000173	45°0′ .000167	45°36′ .000162	46°15′ .000157	46°48′ .000152	47°23′ .000147	47°57′ .000142	48°30′ .000138	49°2′ .000133	49°34′ .000129
47	38°12′ .000220	38°56′ .000213	39°41′ .000206	40°23′ .000200	41°6′ .000194	41°48′ .000188	42°27′ .000182	43°6′ .000176	43°46′ .000171	44°24′ .000165	45°0′ .000160	45°38′ .000155	46°12′ .000150	46°46′ .000146	47°20′ .000141	47°53′ .000137	48°23′ .000132	48°59′ .000128
48	37°38′ .000216	38°23′ .000209	39°6′ .000203	39°49′ .000197	40°30′ .000191	41°11′ .000185	41°50′ .000180	42°31′ .000174	43°10′ .000168	43°45′ .000163	44°25′ .000158	45°0′ .000153	45°34′ .000149	46°9′ .000144	46°44′ .000140	47°18′ .000135	47°50′ .000131	48°22′ .000127

Table No. 8—Continued
Limits 54 Feet Out 48 Feet Down

As the table is given in even feet only, it may be desired to figure the illumination for fractional parts of a foot, in which case the formula $I = \frac{C.P.}{H^2} \cos^3\theta$ will be used with the following values of $\cos^3\theta$:

I = Illumination.
C. P. = Candle-power in the direction of the investigated point.
H = Height of lamp above plane in which point lies.
θ = Angle made by perpendicular dropped from lamp and light ray to point.

TABLE No. 9

Table of Cosines Cubed

Angle Degrees	$\cos^3$	Angle Degrees	$\cos^3$	Angle Degrees	$\cos^3$
1	1.000	29	.668	57	.161
2	.998	30	.649	58	.149
3	.995	31	.630	59	.137
4	.993	32	.610	60	.125
5	.988	33	.590	61	.114
6	.983	34	.570	62	.103
7	.978	35	.550	63	.0936
8	.971	36	.529	64	.0842
9	.963	37	.509	65	.0754
10	.955	38	.489	66	.0671
11	.945	39	.469	67	.0596
12	.935	40	.449	68	.0526
13	.925	41	.429	69	.0460
14	.913	42	.410	70	.0400
15	.901	43	.391	71	.0345
16	.888	44	.372	72	.0295
17	.874	45	.353	73	.0250
18	.860	46	.335	74	.0209
19	.845	47	.317	75	.0173
20	.829	48	.300	76	.0142
21	.813	49	.282	77	.0114
22	.797	50	.265	78	.00900
23	.780	51	.249	79	.00695
24	.762	52	.233	80	.00523
25	.744	53	.218	81	.00383
26	.726	54	.203	82	.00270
27	.707	55	.189	83	.00181
28	.688	56	.175	84	.00114

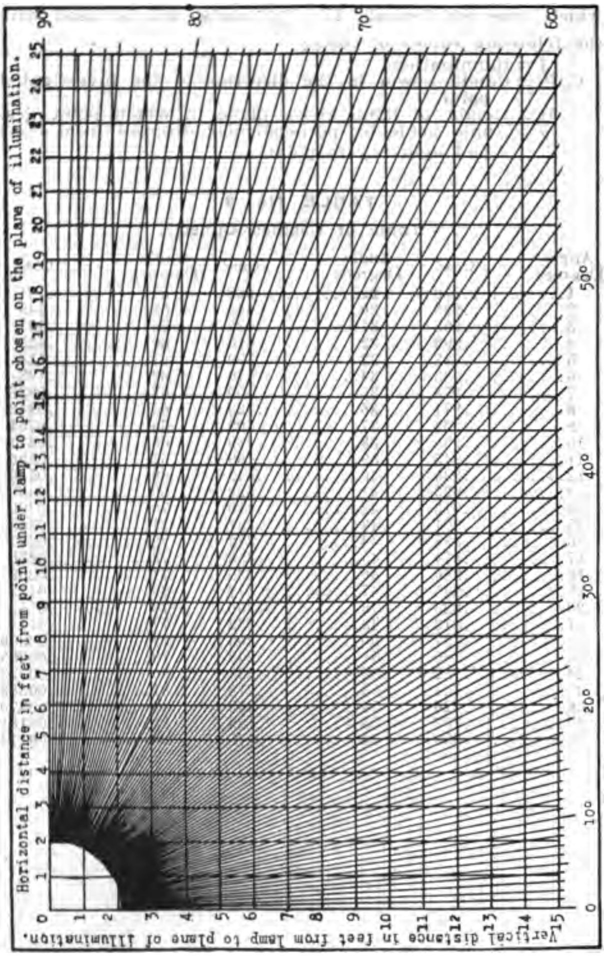

Horizontal distance in feet from point under lamp to point chosen on the plane of illumination.
Vertical distance in feet from lamp to plane of illumination.
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
0° 10° 20° 30° 40° 50° 60° 70° 80° 90°

Fig. 10

With the table above given and the formula it is possible to find the illumination at any point in a room. If there are a number of units all supplying the illumination in a room, the illumination at some particular point would be the sum of the values produced by each lamp. The same operation can be repeated for as many points as desired in the room including all units within such radius that computed results affect materially the resultant value. The illumination in foot-candles at all the points taken should equal as nearly as possible a constant value. This value may be raised by different spacing of units and different types of reflectors.

The importance and value of correctly figuring the proper illumination is not to be underestimated. If a certain light source flickered with a certain maximum and minimum value it would be easier to see by a light that gave the minimum value constantly. If this minimum value were constantly produced in all probability the power consumption would be less. This is analogous to uneven distribution. A uniform system of illumination is more economical because the intensity may be less.

The intensity of illumination required in various places under different conditions is very necessary to the successful working out of illumination problems. This table of intensities is a matter of experience and treats with the consequent recommendations regarding foot-candle intensity and watts per square foot.

Table No. 10

TABLE OF FOOT-CANDLE INTENSITIES RECOMMENDED FOR VARIOUS CLASSES OF SERVICE

	Average Conditions. Foot-Candle Intensity.	Watts per Sq. Ft. Prismatic Glass.	Steel.
Arcade (in addition to light from show windows)	1.0	.240	.....
Armory	2.0	.480	.440
Art gallery (walls)	5.0	1.200	1.100
Auditoriums	2.0	.480	.440
Automobile—			
Garage, large	2.0	.480	.440
Garage, small	2.0	.480	.440
Showroom	5.0	1.200	1.100
Storage room	1.0	.240	.220
Ball room	2.0	.480	.....
Bank (general)	3.0	.720	.....
Bar room	2.5	.600	.....
Barber shop, general (localized lighting provided)	2.0	.480	.....
Barber shop, general (no local lighting provided)	4.0	.960	.....
Bath (Public)—			
Dressing rooms	1.0	.240	.220
Swimming pool	2.0	.480	.440
Billboard	8.0	.....	1.760
Billiard Room—			
General	1.0	.240	.....
Table	5.0	1.200	1.100

Table No. 10—Continued

	Average Conditions. Foot-Candle Intensity.	Watts per Sq. Ft. Prismatic Glass.	Steel.
Bookkeeping	5.0	1.200	1.100
Bowling Alley—			
Alley	1.0	.....	.220
Pins	4.0	.....	.880
Runway and seats	1.5	.360	.....
Cafe	2.5	.600	.....
Card room (tables)	3.0	.720	.660
Carpenter Shop—			
General	2.5	.....	.550
Machinery	4.0	.....	.880
Cars—			
Baggage	1.0	.....	.220
Day coach	2.5	.600	.....
Dining	3.0	.720	.....
Mail	6.0	1.440	1.320
Pullman	2.5	.600	.....
Street	2.5	.600	.....
Corridors	.6	.144	.....
Courts—			
Handball	7.0	1.680	1.540
Squash	7.0	1.680	1.540
Tennis	7.0	1.680	1.540
Courtroom (local lighting for stenographer)	2.0	.480	.....
Church	2.0	.480	.....
Dance hall	2.0	.480	.....
Depot—			
Baggage room	1.0	.240	.220
Train sheds	1.0	.....	.220
Waiting room	2.0	.480	.....
Drafting room	8.0	1.920	1.760
Engraving	10.0	2.400	2.200
Factory—			
General lighting (where individual drop lights are provided)	1.5	.360	.330
General lighting (where no individual drop lights are provided)	4.0	.960	.880
Local bench illumination	4.0	.960	.880
Fire Stations—			
At alarm	3.0	.720	.660
At other times	1.0	.240	.220
Foundry	2.0	.....	.440
Garage	2.0	.480	.440
Gymnasium	2.5	.600	.550
Hallways	.6	.144	.....
Hospital—			
Corridors	.5	.120	.....
Operating table	12.0	2.880	2.640
Wards (with no local illumination supplied	1.5	.360	.....
Wards (with local illumination supplied)	.5	.120	.....

Table No. 10—Continued

	Foot-Candle Intensity.	Average Conditions. Watts per Sq. Ft. Prismatic Glass.	Steel.
Hotels—			
Bed room	2.0	.480	.....
Corridor	1.0	.240	.....
Dining room	2.0	.480	.....
Lobby	2.0	.480	.....
Writing room	3.0	.720	.....
Lavatory	2.0	.480	.440
Laboratory	3.0	.720	.660
Laundry	2.0	.480	.440
Library—			
Stock room	1.5	.360	.330
Reading room (with no local illumination supplied)	3.5	.840	.....
Reading room (with local illumination supplied)	1.0	.240	.....
Lodge room	2.5	.600	.....
Lunch room	2.0	.480	.....
Market	3.0	.720	.660
Mechanical work (fine)	5.5	1.320	1.210
Moving picture theatre (bright)	1.5	.360	.....
Moving picture theatre (dim)	.5	.120	.....
Museum	3.0	.720	.....
Office—			
File room	3.0	.720	.660
Desk	4.0	.960	.....
General (no drop lights)	4.0	.960	.....
General (with drop lights)	1.5	.360	.....
Vault (safe)	3.0	.720	.660
Vault (storage)	1.0	.240	.220
Pattern shops	4.0	.960	.880
Pool room (general)	1.0	.240	.....
Pool table	5.0	1.200	1.100
Power house	2.5	.600	.550
Postal service	7.0	1.680	1.540
Press room	4.0	.960	.880
Reading (ordinary print)	2.5	.600	.....
Reading (fine print)	3.0	.720	.....
Residence—			
Porch	.2	.048	.....
Porch (reading light local)	2.0	.480	.....
Hall (entrance)	.7	.168	.....
Reception room	1.5	.360	.....
Parlor	1.5	.360	.....
Living room	1.5	.360	.....
Library	3.0	.720	.....
Music room	3.0	.720	.....
Dining room	1.5	.360	.....
Pantry	2.0	.480	.....
Kitchen	2.0	.480	.....
Laundry	1.5	.360	.330
Hall (upstairs)	.5	.120	.....

Table No. 10—Continued

	Average Conditions. Foot-Candle Intensity.	Watts per Sq. Ft. Prismatic Glass.	Steel.
Residence—			
Bed room	1.5	.360	.....
Bath room	2.0	.480	.....
Furnace room	1.0	.240	.220
Store room	.5	.120	.110
Restaurant	2.0	.480	.440
Rink (skating)	2.0	.480	.440
Rug rack	6.0	1.440	1.320
Saloon	3.0	.720	.....
School—			
Assembly room	2.0	.480	.....
Class room	3.0	.720	.....
Cloak room	.8	.192	.....
Corridor	.8	.192	.....
Drawing	5.0	1.200	1.100
Laboratory	3.0	.720	.660
Manual training	3.0	.720	.660
Office	3.0	.720	.....
Study room	3.0	.720	.....
Sewing (light goods)	4.0	.960	.880
Sewing (dark goods)	8.0	1.920	1.760
Shipping room	1.5	.360	.330
Show Window—			
Dark goods	20.0	4.800	4.400
Light goods	8.0	1.920	1.760
Medium goods	16.0	3.840	3.520
Sign	8.0	1.920	1.760
Spinning Mills	2.0	.480	.440
Stable	1.0	.240	.220
Stereotyping	4.0	.960	.880
Stock room	1.0	.240	.220
Store—			
Art	4.0	.960	.....
Baker	3.0	.720	.....
Book	3.5	.840	.....
Butcher	3.5	.840	.....
China	2.5	.600	.....
Cigar	5.0	1.200	.....
Clothing	6.0	1.440	.....
Cloak and suit	6.0	1.440	.....
Confectionery	4.0	.960	.....
Decorator	3.0	.720	.....
Department (see each department)			
Drugs	4.0	.960	.....
Dry goods	4.0	.960	.....
Florist (with case lighting)	2.0	.480	.....
Florist (general—no case lighting)	3.0	.720	.....
Furniture	3.5	.840	.....
Furrier	5.0	1.200	.....
Grocery	4.0	.960	.....
Haberdasher	6.5	1.560	.....
Hardware	3.5	.840	.770

Table No. 10—Continued

	Average Conditions. Foot-Candle Intensity.	Watts per Sq. Ft. Prismatic Glass.	Steel.
Store—			
Hat	4.0	.960	.....
Jewelry	6.5	1.560	.....
Lace	4.0	.960	.....
Leather	3.5	.840	.770
Meat	3.5	.840	.....
Men's furnishings	5.5	1.320	.....
Millinery	5.0	1.200	.....
Music	4.5	1.080	.....
Notions	3.0	.720	.....
Piano	4.5	1.080	.....
Post cards	4.0	.960	.....
Shoes	4.0	.960	.....
Stationery	4.0	.960	.....
Tailor	6.0	1.440	.....
Tobacco	5.0	1.200	.....
Street—			
Business (not including light from windows and signs)	.5	.120	.110
Country roads	.05	.012	.011
Prominent (in residence district)	.2	.048	.044
Residence	.1	.024	.022
Studio	4.0	.960	.....
Telephone exchange (with board lighting)	1.5	.360	.330
Theatre—			
Auditorium	2.0	.480	.....
Foyer	2.0	.480	.....
Lobby	5.0	1.200	.....
Typesetting	8.0	1.920	1.760
Warehouse	1.0	.240	.220
Wharf	1.0	.240	.220
Weaving—			
Cotton, light colors	2.5	.600	.550
Cotton, dark colors	4.0	.960	.880
Wool, light colors	3.0	.720	.660
Wool, dark colors	5.0	1.200	1.100
Silk, light colors	4.0	.900	.880
Silk, dark colors	6.0	1.440	1.320

RAPID CALCULATION OF ILLUMINATION

The method of determining illumination as previously described is excessively tedious and takes considerable time. Upon the basis of the lumen (which is the quantity of light flux emanating from a light source required to illuminate a square foot area equally to an intensity of one foot-candle) a method has been developed for quickly determining the wattage required to illuminate a certain area to a given intensity and the reverse.

An incandescent lamp has a certain number of lumens for each watt of power, the number being determined by 12.57 times the mean spherical candle-power per watt. A unit source of one mean spherical candle-power emits 12.57 lumens. However, only a certain portion of the total lumens of the source are useful in producing illumination due to the absorption of the reflector or directing medium

and the absorption of the walls and ceiling. The ratio of the lumens effective on the plane of illumination to the total light from the unit may be termed for convenience "the utilization factor." The most useful of these are embodied in the table given below.

Table No. 11

UTILIZATION FACTORS

Unit	Walls Light	Walls Medium	Walls Dark
Prismatic Glass	.60	.50	.40
Opal or Milk Glass	.50	.42	.38
Decorative or Art Glass	.30	.25	.20
Semi-indirect	.40	.35	.30
Indirect	..	.33	..
	Wide		Narrow
*Steel	.58		.50

The quantity of light effective in producing illumination is known as the effective lumens from the light source.

To find the illumination in a given room with a certain number of units, the effective lumens of which you know, the procedure would be to multiply the number of units by the effective lumens per lamp and divide by the area. This would give the number of lumens per square foot or the foot-candle intensity.

On the curve sheets following the effective lumens given have been computed for condition of dark walls and ceiling. For average conditions 15% may be added to the value given and for light walls and ceiling 20% should be added.

To find the number of units required to give a certain intensity the reverse operation is made, i. e., multiply the area in square feet by the intensity desired and divide by the effective lumens per lamp.

As it is quite out of the question to include the effective lumens obtained from every combination of reflectors and lamps, the method of obtaining the wattage or intensity has been further simplified by obtaining average effective lumens for different classes of lighting and with the two principal materials, glass and steel. This has been reduced in terms of watts per square foot as a definite number of lumens is emitted from any certain lamp, per watt. These values can be found in the above table in connection with the intensity produced. These values, however, are for average conditions, and in cases where extreme light or dark conditions prevail they should be modified according to the following:

For light conditions subtract 10% from the value of watts per square foot given.

For dark conditions add 10% to the value of watts per square foot given.

In considering illumination there is a definite plane upon which this light is desired which is very seldom the plane of the floor. This "reference plane" or "plane of illumination" is usually the height above the floor at which work is carried on; the plane of desk tops, benches, counters, layout tables, etc. In most cases this is approximately 2 feet 6 inches above the floor. All values as to mounting height of reflectors should be taken from this as a basis.

*Values for steel will vary 10% either way depending upon conditions. They hold only when ratio of mounting height to smallest dimension of room is not greater than 1:2.

Spacing and mounting height of reflectors are interdependent. There are two cases which must be dealt with, one when outlets are already located and the other where outlets must be located. The first has only to do with the proper mounting height while the second has to do with the proper placing of outlets as well as the proper suspension of the units.

Table No, 12

Prismatic Glass			Translucent or Opal Glass		Steel	
Ext.	Int.	Foc.	Flat	Bowl	Dome	Bowl
.5D	.8D	1.3D	.6D	.8D	.67D	.8D

There is no definite rule that can be laid down relative to the spacing of lighting units. A few general rules governing this may be given however.

(a) The area should be divided as nearly as possible into squares with units located at the center of each. The size of square depends upon architectural restrictions and the size of the illuminating unit.

(b) Units should be systematically located around posts in order to avoid shadows.

(c) Units should be systematically located with regard to deep beams in order that awkward shadows may be avoided.

The mounting height, as before stated, depends upon the spacing of the units and their distribution curves. The correct mounting height and allowable variation is given as a proportional part of the spacing on each of the distribution curves following.

In general, reflectors may be classified as prismatic, translucent or opal glass, and steel; and the mounting heights shown above are to be recommended.

In some cases it will be found impossible to adhere to the mounting heights given, in which case they may be varied by .1D without materially affecting the resulting illumination.

As a matter of convenience distribution curves of reflectors of various manufacturers are shown. It is obvious that no comparison of the different makes can be shown in a book of this character.

On each * distribution curve will be found the effective lumens per lamp, efficiency of the reflector, its value in directing light in the lower hemisphere and the mounting height given in a fractional part of the spacing.

*The curves with the accompanying data will change from time to time as the efficiency of the lamp changes. The magnitude of the change will be in the ratio of the mean horizontal candle-powers.

Example Problem Worked Out by the Methods Above Given

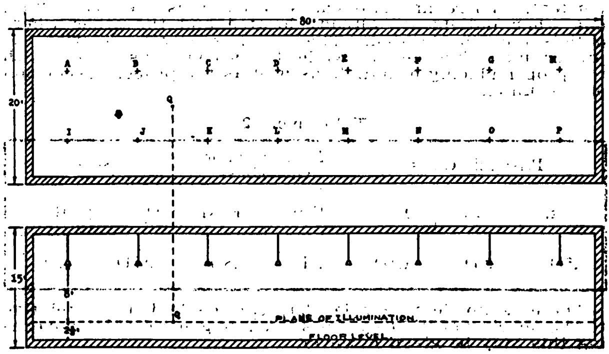


Fig. 11

To figure illumination at Q from the light sources represented by A, B, C, etc., each unit to consist of one 100-watt bowl-frosted Mazda lamp, fitted with prismatic reflector as shown on page 186. Units hanging 10½ ft. above the floor or 8 ft. above the plane of illumination. Light Conditions.

By the Illumination Table: By scaling the diagram we find that Q is approximately 17 ft. from A, and as the plane of illumination is 8 ft. below the lamps, the constant desired will be found 17 ft. out and 8 ft. down, which is .001210, the angle of the light ray 64° 48' or 65° (the nearest degree can be taken). By referring to the distribution curve, page 186, the candle-power at 65° is found to be 55.0, which, when multiplied by .0012100, gives the illumination, .066, from A at point Q. But I, D, and L produce the same illumination, being the same distance away, consequently this value must be multiplied by four, which is .267 foot-candles.

Again, B is approximately 7 ft. from Q and the value at 7 ft. out and 8 ft. down when multiplied by the candle-power at the given angle, then will represent the illumination from B, C, J, and K. So the illumination is calculated for each point and the sum of all values obtained is the resultant illumination at Q from all lamps.

By the Formulæ: Suppose the scale distance from M to Q to be 24½ ft., Q being 8 ft. below the light source. This is the same at 4 and 12¼ ft.; looking up the angle on the chart, page 174, it is found to be 72°. The candle-power corresponding to this angle on page 186 is 42. The $\cos^3\theta$ of the nearest angle is .0295. Substituting in the formula $I = \frac{CP}{H^2} \times \cos^3\theta$, the illumination is $\frac{42}{62} \times .0295 = .0195$ foot-candles. This may be followed out as many times as is necessary to obtain the resulting illumination.

Lumen Method of Determining Illumination: The area considered is 80 × 20 or 1600 sq. ft. The effective lumens per unit considered is 395. Multiplying the effective lumens per unit by the number of units (16) gives the total lumens

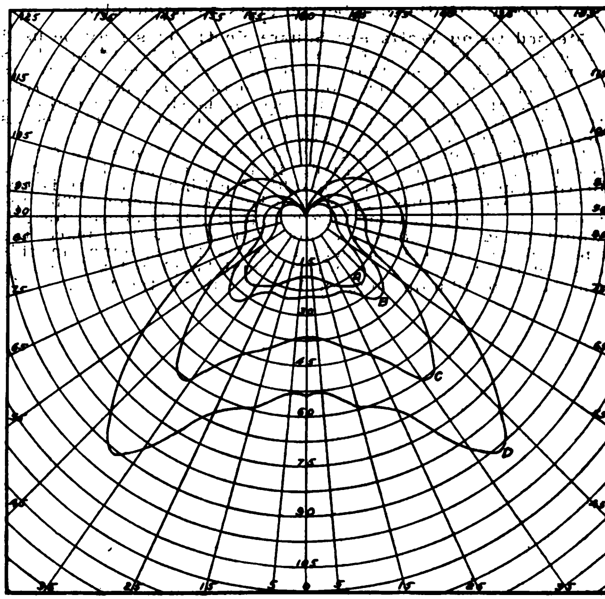
delivered to produce illumination (6320), which, when divided by the area (1600 sq. ft.), results in lumens per sq. ft. or a foot-candle intensity of 3.95, plus 20% of which equals approximately 4.75 foot-candles.

The reverse can be followed out if the area and intensity are known with the number of units to be decided.

Method Using Watts Per Square Foot: This may be used in determining quickly the intensity in a given room. It is seen from the table that under light conditions .216 watts per square foot produces one foot-candle intensity. Given the area and the wattage as 1600, it is simple to estimate the intensity at approximately 4.75 foot-candles. This is, as before stated, an approximation only.

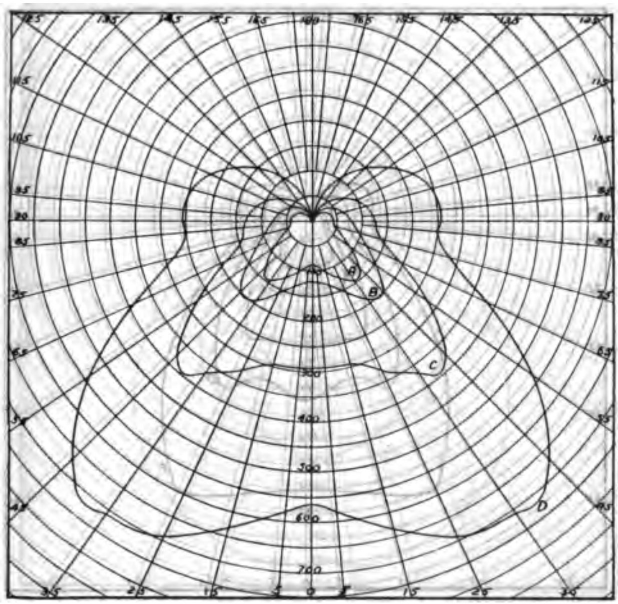
The subject of mounting height would be the same for all problems. From the drawing it is seen that the spacing of the lamps is 10 ft., the height of ceiling 15 ft. It is desired to find the best type of prismatic reflector. The intensive type with a mounting height of .8D is chosen for .5D would bring the units too low and 1.3D would place the units above the ceiling height. D is the spacing, in this case 10 ft.; therefore the units would be placed 8 ft. above the plane of illumination, or 10½ ft. above the floor.

CANDLE-POWER DISTRIBUTION CURVES FOR HOLOPHANE PRISMATIC REFLECTORS



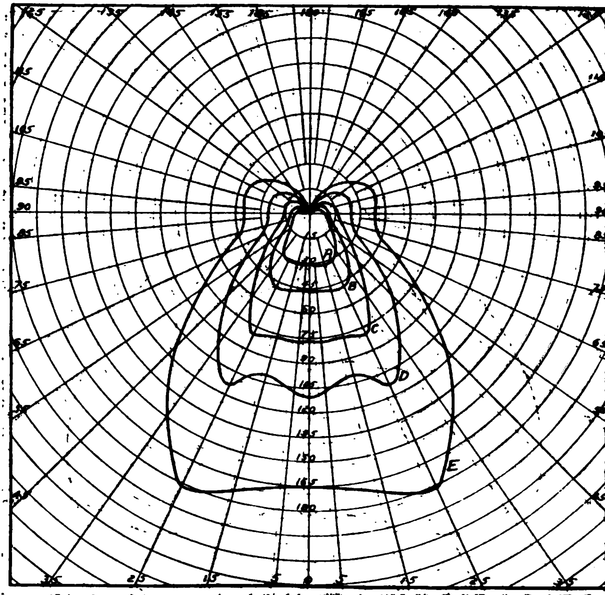
No. of Curve	A	B	C	D
Size of Lamp (Watts)	20	25	40	60
No. of Reflector	XE-20	XE-25	XE-40	XE-60
Effective Lumens per Lamp	67.8	85.0	144	220
Efficiency of Reflector (%) $\left\{\dfrac{\text{MSCP (R)}}{\text{MSCP (L)}}\right\}$	83.1	82.9	84.5	86.9
Value as a Reflector (%) $\left\{\dfrac{\text{MLHCP (R)}}{\text{MLHCP (L)}}\right\}$	134.8	131.6	133.7	140.3
Mounting Height	.5D	.5D	.5D	.5D
D—Average spacing of outlets.				
Allowable variation in mounting height	.1D	±.1D	±.1D	±.1D

CANDLE-POWER DISTRIBUTION CURVES FOR HOLOPHANE PRISMATIC REFLECTORS—(Continued)



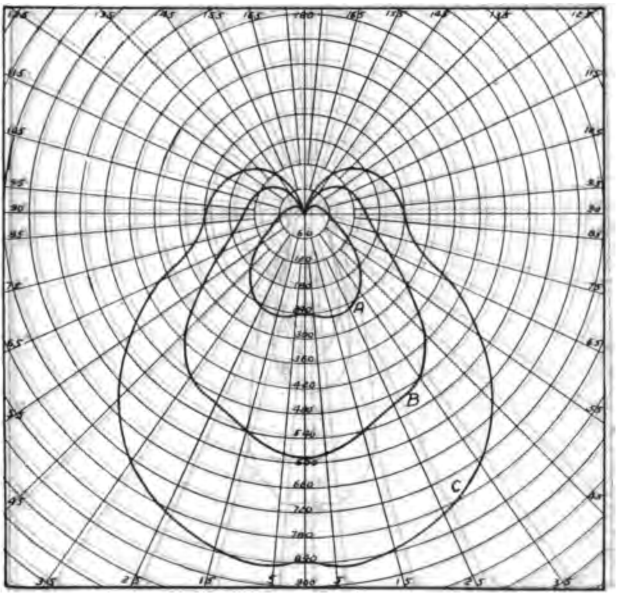
No. of Curve	A	B	C	D
Size of Lamp (Watts)	100	150	250	500
No. of Reflector	XE-100	XE-150	XE-250	XE-500
Effective Lumens per Lamp	367	540	1020	2000
Efficiency of Reflector (%) $\left\{\frac{\text{MSCP (R)}}{\text{MSCP (L)}}\right\}$	87.1	88.8	86.5	86.1
Value as a Reflector (%) $\left\{\frac{\text{MLHCP (R)}}{\text{MLHCP (L)}}\right\}$	135.6	139.0	142.0	137.0
Mounting Height	.5D	.5D	.5D	.5D
D—Average spacing of outlets.				
Allowable variation in mounting height	±.1D	±.1D	±.1D	±.1D

CANDLE-POWER DISTRIBUTION CURVES FOR HOLOPHANE PRISMATIC REFLECTORS—(Continued)



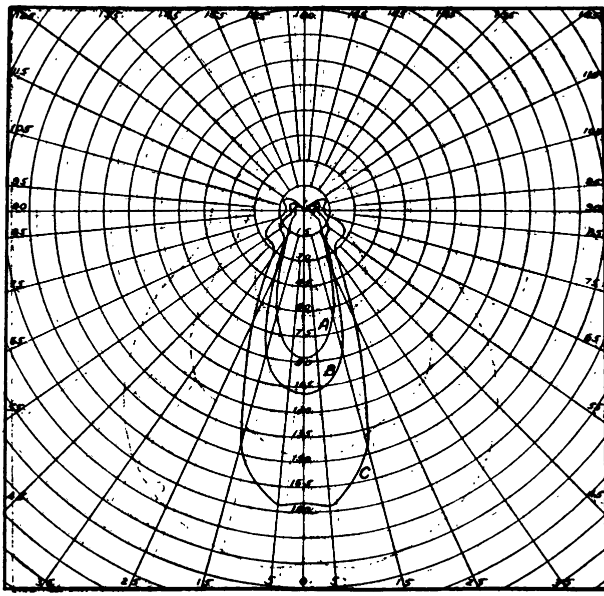
No. of Curve	A	B	C	D	E
Size of Lamp (Watts)	20	25	40	60	100
No. of Reflector	XI-20	XI-25	XI-40	XI-60	XI-100
Effective Lumens per Lamp	71.4	102.0	158.0	246.0	395.0
Efficiency of Reflector (%) $\left\{\frac{\text{MSCP (R)}}{\text{MSCP (L)}}\right\}$	82.2	84.7	84.5	87.5	87.5
Value as a Reflector (%) $\left\{\frac{\text{MLHCP (R)}}{\text{MLHCP (L)}}\right\}$	136.0	139.0	136.0	144.0	136.0
Mounting Height	.8D	.8D	.8D	.8D	.8D
D—Average spacing of outlets.					
Allowable variation in mounting height	±.1D	±.1D	±.1D	±.1D	±.1D

CANDLE-POWER DISTRIBUTION CURVES FOR HOLOPHANE PRISMATIC REFLECTORS—(Continued)



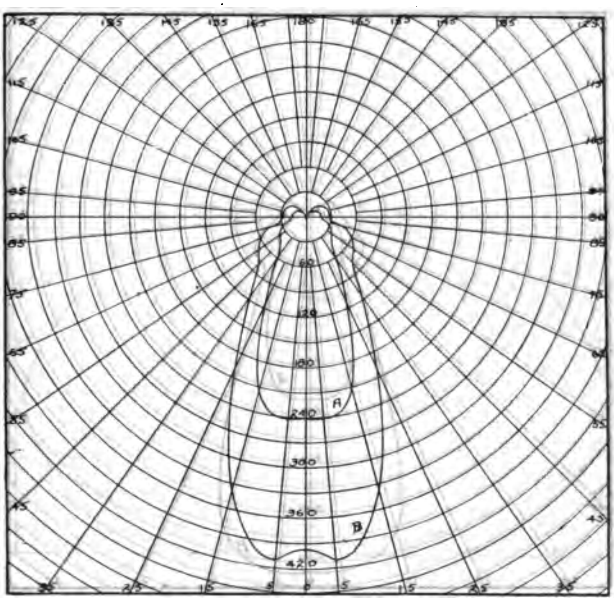
No. of Curve	A	B	C
Size of Lamp (Watts)	150	250	500
No. of Reflector	XI-150	XI-250	XI-500
Effective Lumens per Lamp	629	1060	2090
Efficiency of Reflector (%) $\left\{\frac{\text{MSCP (R)}}{\text{MSCP (L)}}\right\}$	85.7	87.1	86.1
Value as a Reflector (%) $\left\{\frac{\text{MLHCP (R)}}{\text{MLHCP (L)}}\right\}$	143.0	144.2	140.0
Mounting Height	.8D	.8D	.8D
D—Average spacing of outlets.			
Allowable variation in mounting height	±.1D	±.1D	±.1D

CANDLE-POWER DISTRIBUTION CURVES FOR HOLOPHANE PRISMATIC REFLECTORS—(Continued)



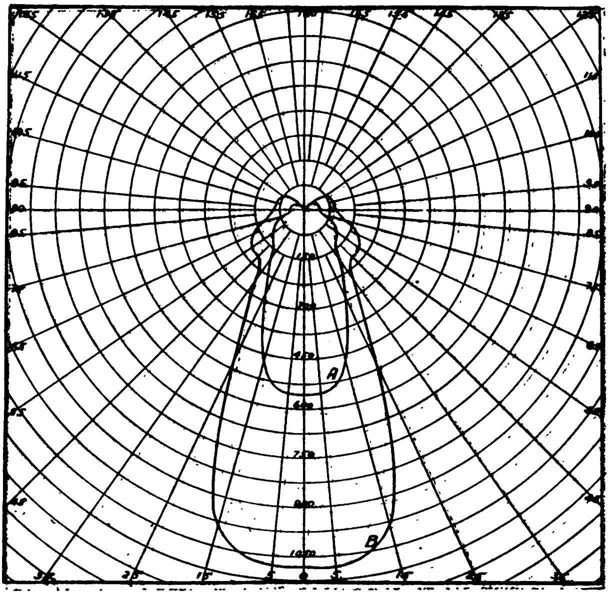
No. of Curve	A	B	C
Size of Lamp (Watts)	20	25	40
No. of Reflector	XF-20	XF-25	XF-40
Effective Lumens per Lamp	83.6	99.0	145.2
Efficiency of Reflector (%) $\left\{\frac{\text{MSCP (R)}}{\text{MSCP (L)}}\right\}$	81.5	82.3	86.8
Value as a Reflector (%) $\left\{\frac{\text{MLHCP (R)}}{\text{MLHCP (L)}}\right\}$	137.4	133.5	141.2
Mounting Height	1.33D	1.33D	1.33D
D—Average spacing of outlets			
Allowable variation in mounting height	±.1D	±.1D	±.1D

CANDLE-POWER DISTRIBUTION CURVES FOR HOLOPHANE PRISMATIC REFLECTORS—(Continued)



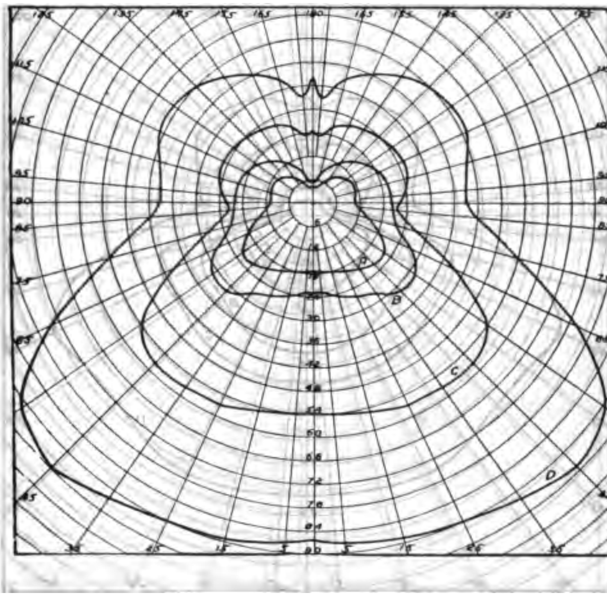
No. of Curve	A	B
Size of Lamp (Watts)	60	100
No. of Reflector	XF-60	XF-100
Effective Lumens per Lamp	246	425
Efficiency of Reflector (%) $\left\{\dfrac{\text{MSCP (R)}}{\text{MSCP (L)}}\right\}$	86.5	85.0
Value as a Reflector (%) $\left\{\dfrac{\text{MLHCP (R)}}{\text{MLHCP (L)}}\right\}$	145.0	143.5
Mounting Height	1.33D	1.33D
D—Average spacing of outlets.		
Allowable variation in mounting height	.1D	.1D

CANDLE-POWER DISTRIBUTION CURVES FOR HOLOPHANE PRISMATIC REFLECTORS—(Continued)



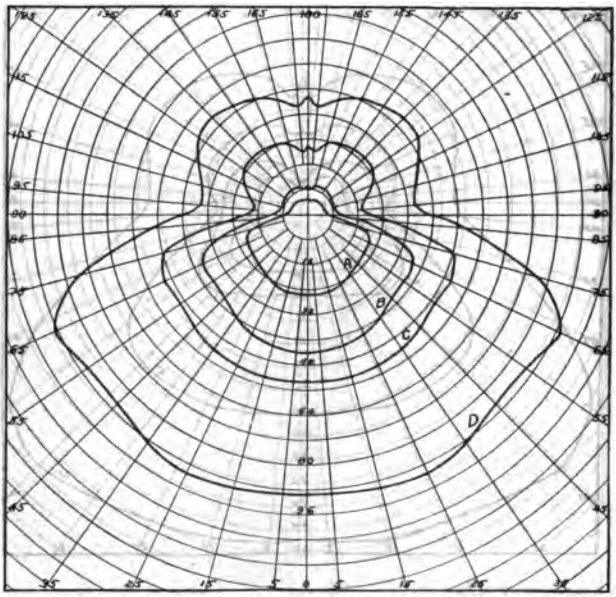
No. of Curve	A	B
Size of Lamp (Watts)	150	250
No. of Reflector	XF-150	XF-250
Effective Lumens per Lamp	649	1115
Efficiency of Reflector (%) $\left\{\frac{\text{MSCP (R)}}{\text{MSCP (L)}}\right\}$	86.1	84.6
Value as a Reflector (%) $\left\{\frac{\text{MLHCP (R)}}{\text{MLHCP (L)}}\right\}$	142.0	143.8
Mounting Height	1.33D	1.33D
D—Average spacing of outlets.		
Allowable variation in mounting height	±.1D	±.1D

CANDLE-POWER DISTRIBUTION CURVES FOR FOSTORIA VELURIA REFLECTORS



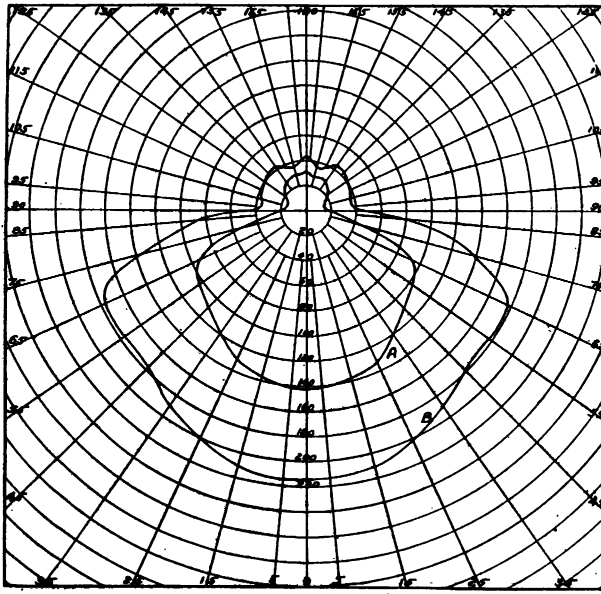
No. of Curve	A	B	C	D.
Size of Lamp (Watts)	25	40	60	100
No. of Reflector	0462	0462	0462	0462
Size of Reflector (Inches dia.)	5″	5″	7″	7″
Effective Lumens per Lamp	67	92.5	176.0	2885
Efficiency of Reflector (%) $\left\{\frac{\text{MSCP (R)}}{\text{MSCP (L)}}\right\}$	91.3	82.3	84.3	84.0
Value as a Reflector (%) $\left\{\frac{\text{MLHCP (R)}}{\text{MLHCP (L)}}\right\}$	127.8	116.8	123.3	124.5
Mounting Height	.8D	.8D	.8D	.8D
D—Average spacing of outlets.				
Allowable variation in mounting height	±.1D	±.1D	±.1D	±.1D

CANDLE-POWER DISTRIBUTION CURVES FOR FOSTORIA VELURIA REFLECTORS—(Continued)



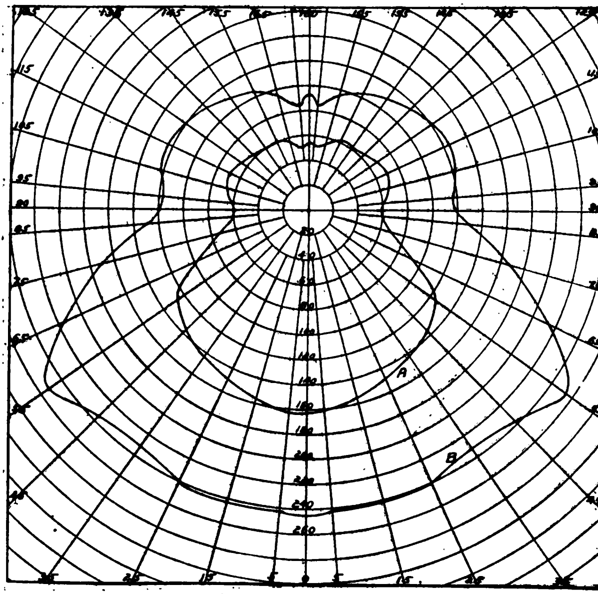
No. of Curve	A	B	C	D
Size of Lamp (Watts)	25	40	60	100
No. of Reflector	01129	01129	01129	01129
Size of Reflector (Inches dia.)	7″	7″	9″	9″
Effective Lumens per Lamp	70.5	126.4	162.8	278
Efficiency of Reflector (%) $\left\{\frac{\text{MSCP (R)}}{\text{MSCP (L)}}\right\}$	84.8	82.7	87.4	87.4
Value as a Reflector (%) $\left\{\frac{\text{MLHCP (R)}}{\text{MLHCP (L)}}\right\}$	146.0	150.5	136.3	135.1
Mounting Height	.6D	.6D	.6D	.6D
D—Average spacing of outlets.				
Allowable variation in mounting height	±.1D	±.1D	±.1D	±.1D

CANDLE-POWER DISTRIBUTION CURVES FOR FOSTORIA VELURIA REFLECTORS—(Continued)



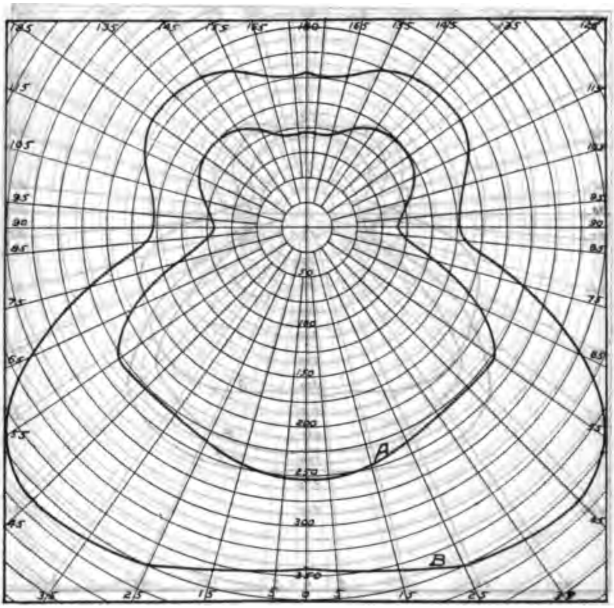
No. of Curve	A	B
Size of Lamp (Watts)	100	150
No. of Reflector	01141	01141
Size of Reflector (Inches dia.)	11″	11″
Effective Lumens per Lamp	363	497
Efficiency of Reflector (%) $\left\{\frac{\text{MSCP (R)}}{\text{MSCP (L)}}\right\}$	79.0	84.3
Value as a Reflector (%) $\left\{\frac{\text{MLHCP (R)}}{\text{MLHCP (L)}}\right\}$	146.0	155.3
Mounting Height	.6D	.6D
D—Average spacing of outlets.		
Allowable variation in mounting height	±.1D	±.1D

CANDLE-POWER DISTRIBUTION CURVES FOR FOSTORIA VELURIA REFLECTORS—(Continued)



No. of Curve	A	B
Size of Lamp (Watts)	150	250
No. of Reflector	01140	01140
Size of Reflector (Inches dia.)	11"	11"
Effective Lumens per Lamp	438	762
Efficiency of Reflector (%) $\left\{\frac{\text{MSCP (R)}}{\text{MSCP (L)}}\right\}$	87.4	88.5
Value as a Reflector (%) $\left\{\frac{\text{MLHCP (R)}}{\text{MLHCP (L)}}\right\}$	126.1	131.5
Mounting Height	.8D	.8D
D—Average spacing of outlets.		
Allowable variation in mounting height	±.1D	±.1D

CANDLE-POWER DISTRIBUTION CURVES FOR FOSTORIA VELURIA REFLECTORS—(Continued)

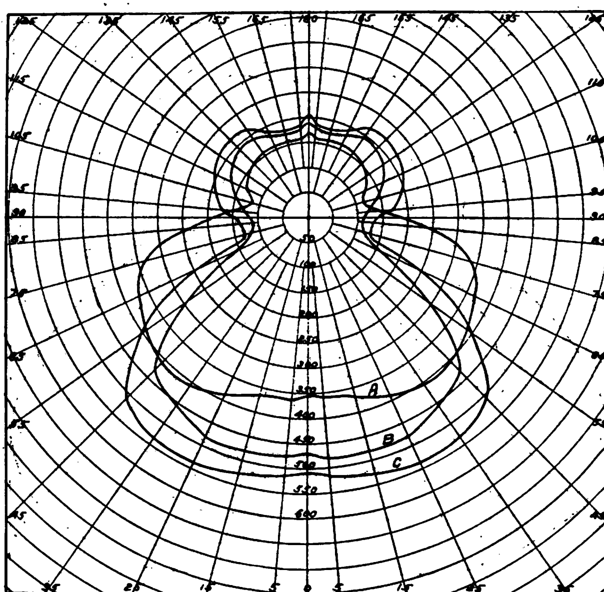


No. of Curve	A	B
Size of Lamp (Watts)	250	400
No. of Reflector	01140	01140
Size of Reflector (Inches dia.)	12"	12"
Effective Lumens per Lamp	726	1178
Efficiency of Reflector (%) $\left\{\frac{\text{MSCP (R)}}{\text{MSCP (L)}}\right\}$	81.7	79.4
Value as a Reflector (%) $\left\{\frac{\text{MLHCP (R)}}{\text{MLHCP (L)}}\right\}$	117.5	114.6
Mounting Height	.8D	.8D

D—Average spacing of outlets.

Allowable variation in mounting height	±.1D	±.1D

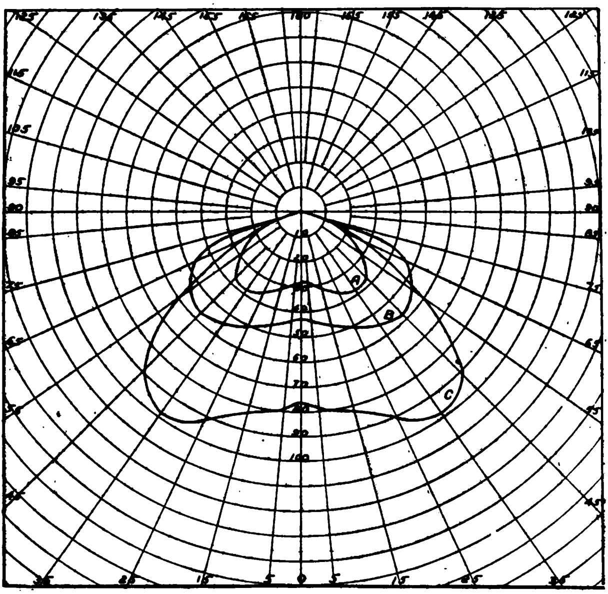
CANDLE-POWER DISTRIBUTION CURVES FOR FOSTORIA VELURIA REFLECTORS—(Continued)



No. of Curve	A	B	C
Size of Lamp (Watts)	400	400	500
No. of Reflector	01141	*01141	*01141
Size of Reflector (Inches dia.)	15″	14″	14″
Effective Lumens per Lamp	1240	1210	1510
Efficiency of Reflector (%) $\left\{\frac{\text{MSCP (R)}}{\text{MSCP (L)}}\right\}$	83.0	72.4	70.3
Value as a Reflector (%) $\left\{\frac{\text{MLHCP (R)}}{\text{MLHCP (L)}}\right\}$	134.3	101.3	102.0
Mounting Height	.6D	.8D	.8D
D—Average spacing of outlets.			
Allowable variation in mounting height	±.1D	±.1D	±.1D

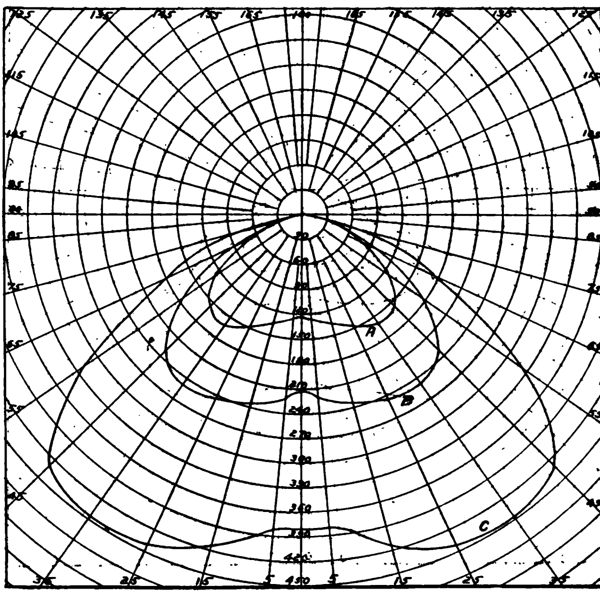
*Heavy weight.

CANDLE-POWER DISTRIBUTION CURVES FOR HOLOPHANE ENAMELED STEEL REFLECTORS



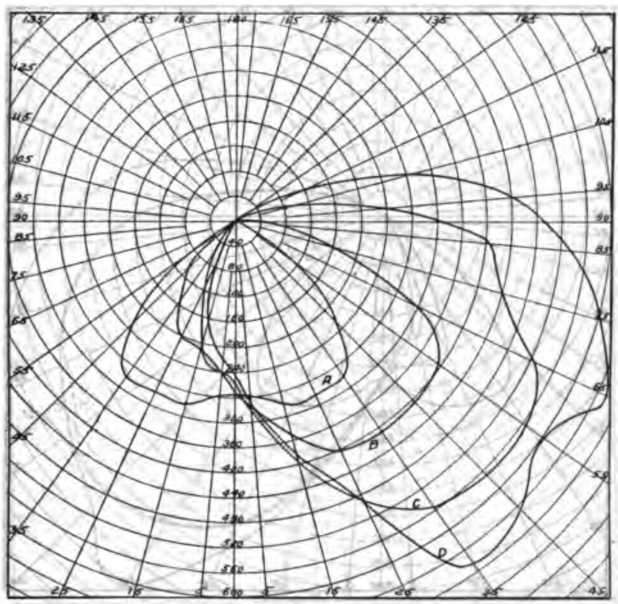
No. of Curve	A	B	C
Size of Lamp (Watts)	25	40	60
No. of Reflector	SEE-40	SEE-40	SEE-60
Size of Reflector (Inches dia.)	6¼"	6¼"	7¼"
Effective Lumens per Lamp	114.2	167.5	260.0
Efficiency of Reflector (%) $\left\{\frac{\text{MSCP (R)}}{\text{MSCP (L)}}\right\}$	63.5	67.0	59.5
Value as a Reflector (%) $\left\{\frac{\text{MLHCP (R)}}{\text{MLHCP (L)}}\right\}$	121.0	132.8	116.3
Mounting Height	.8D	.8D	.8D
D—Average spacing of outlets.			
Allowable variation in mounting height	±.1D	±.1D	±.1D

CANDLE-POWER DISTRIBUTION CURVES FOR HOLOPHANE ENAMELED STEEL REFLECTORS—(Continued)



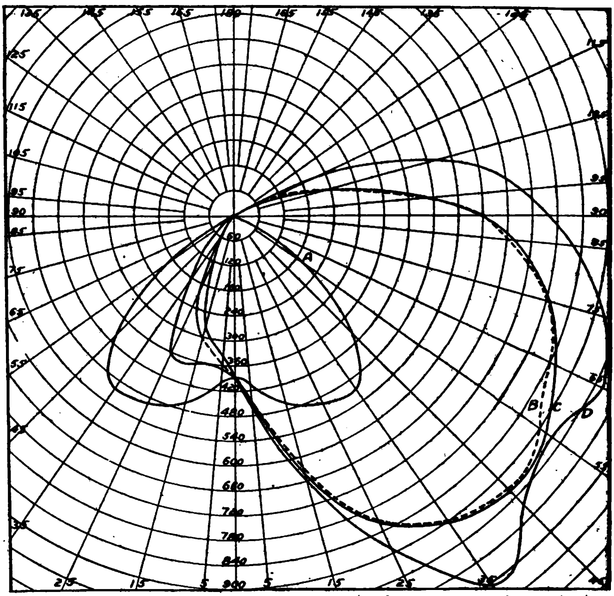
No. of Curve	A	B	C
Size of Lamp (Watts)	100	150	250
No. of Reflector	SEE-100	SEE-150	SEE-250
Size of Reflector (Inches dia.)	8¼″	10¼″	10¼″
Effective Lumens per Lamp	457	695	1260
Efficiency of Reflector (%) $\left\{\frac{\text{MSCP (R)}}{\text{MSCP (L)}}\right\}$	64.0	63.3	63.1
Value as a Reflector (%) $\left\{\frac{\text{MLHCP (R)}}{\text{MLHCP (L)}}\right\}$	125.5	124.2	125.4
Mounting Height	.8D	.8D	.8D
D—Average spacing of outlets.			
Allowable variation in mounting height	±.1D	±.1D	±.1D

CANDLE-POWER DISTRIBUTION CURVES FOR ASYMMETRICAL REFLECTORS



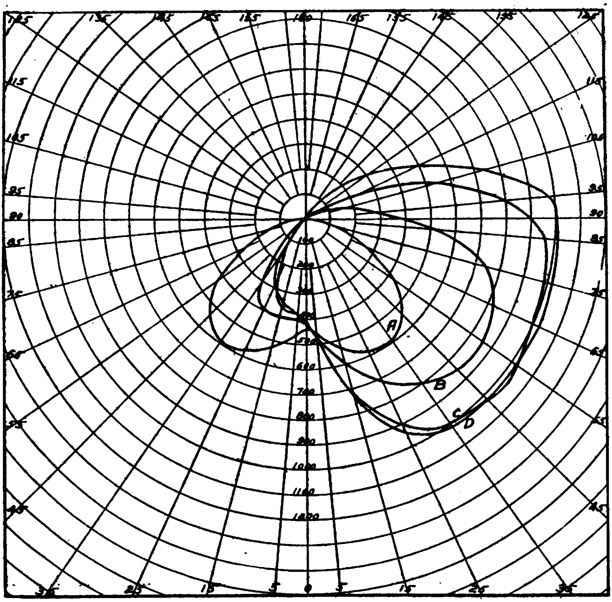
No. of Curve	A	B	C	D
Size of Lamp (Watts)	250	250	250	250
Direction relative to wall	Parallel	30°	60°	Perpen.
Effective Lumens per Lamp	....	....	....	....
Efficiency of Reflector (%) $\left\{\frac{\text{MSCP (R)}}{\text{MSCP (L)}}\right\}$	....	....	....	....
Value as a Reflector (%) $\left\{\frac{\text{MLHCP (R)}}{\text{MLHCP (L)}}\right\}$	....	....	....	....
Mounting Height	.33D	.33D	.33D	.33D
D—Average spacing of outlets.				
Allowable variation in mounting height	±.1D	±.1D	±.1D	±.1D

CANDLE-POWER DISTRIBUTION CURVES FOR ASYMMETRICAL REFLECTORS—(Continued)



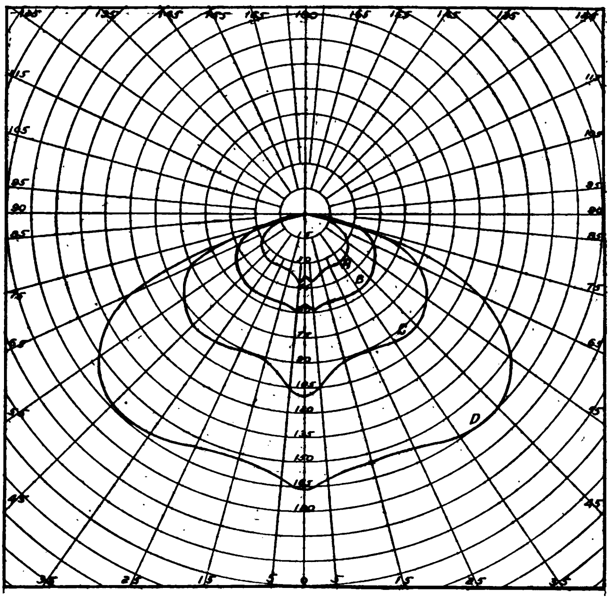
No. of Curve	A	B	C	D
Size of Lamp (Watts)	400	400	400	400
Direction relative to wall	Parallel	30°	60°	Perpen.
Effective Lumens per Lamp	....	....	....	....
Efficiency of Reflector (%) $\left\{\frac{\text{MSCP (R)}}{\text{MSCP (L)}}\right\}$	....	....	....	....
Value as a Reflector (%) $\left\{\frac{\text{MLHCP (R)}}{\text{MLHCP (L)}}\right\}$	....	....	....	....
Mounting Height	.33D	.33D	.33D	.33D
D—Average spacing of outlets.				
Allowable variation in mounting height	±.1D	±.1D	±.1D	±.1D

CANDLE-POWER DISTRIBUTION CURVES FOR ASYMMETRICAL REFLECTORS—(Continued)



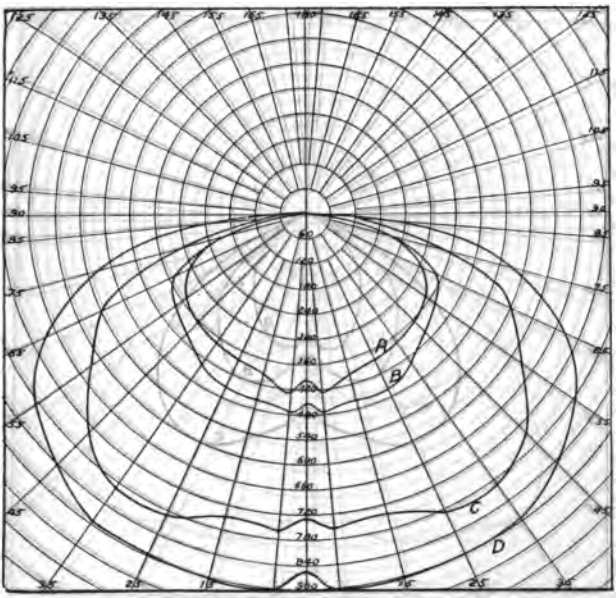
No. of Curve	A	B	C	D
Size of Lamp (Watts)	500	500	500	500
Direction relative to wall	Parallel	30°	60°	Perpen.
Effective Lumens per Lamp	....	....	....	....
Efficiency of Reflector (%) $\left\{\frac{\text{MSCP (R)}}{\text{MSCP (L)}}\right\}$	....	....	....	....
Value as a Reflector (%) $\left\{\frac{\text{MLHCP (R)}}{\text{MLHCP (L)}}\right\}$	....	....	....	....
Mounting Height	.33D	.33D	.33D	.33D
D—Average spacing of outlets.				
Allowable variation in mounting height	±.1D	±.1D	±.1D	±.1D

CANDLE-POWER DISTRIBUTION CURVES FOR DOME TYPE REFLECTORS



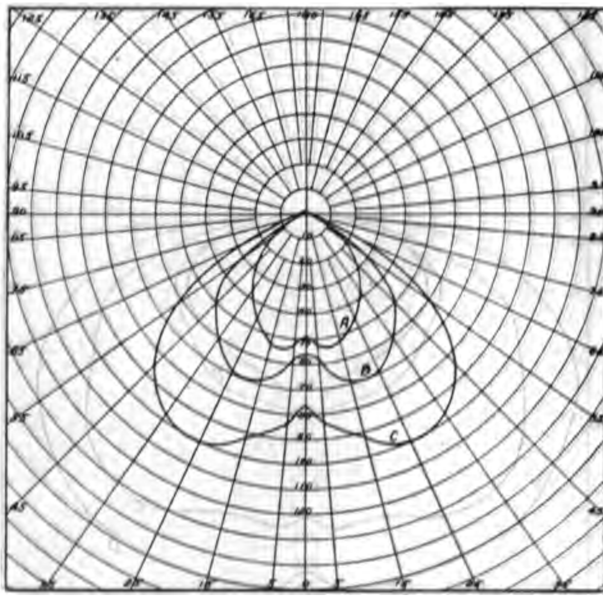
No. of Curve	A	B	C	D
Size of Lamp (Watts)	25	40	60	100
Size of Reflector (Inches dia.)	12″	12″	15″	18″
Effective Lumens per Lamp	112	168	261	497
Efficiency of Reflector (%) $\left\{\frac{\text{MSCP (R)}}{\text{MSCP (L)}}\right\}$	72.6	75.8	74.0	73.1
Value as a Reflector (%) $\left\{\frac{\text{MLHCP (R)}}{\text{MLHCP (L)}}\right\}$	139.9	150.0	146.0	141.5
Mounting Height	.67D	.67D	.67D	.67D
D—Average spacing of outlets.				
Allowable variation in mounting height	±.1D	±.1D	±.1D	±.1D

CANDLE-POWER DISTRIBUTION CURVES FOR DOME TYPE REFLECTORS—(Continued)



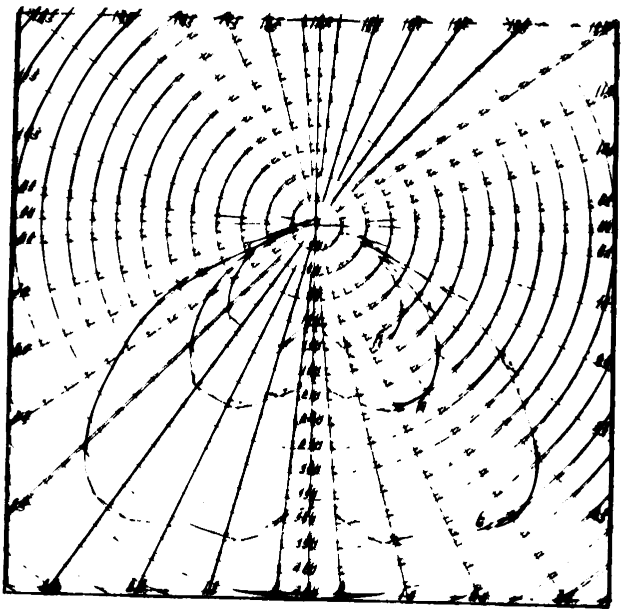
No. of Curve	A	B	C	D
Size of Lamp (Watts)	250	250	400	500
Size of Reflector (Inches dia.)	20″	18″	20″	20″
Effective Lumens per Lamp	1315	1161	2280	2705
Efficiency of Reflector (%) $\left\{\frac{\text{MSCP (R)}}{\text{MSCP (L)}}\right\}$	79.5	74.3	80.1	81.3
Value as a Reflector (%) $\left\{\frac{\text{MLHCP (R)}}{\text{MLHCP (L)}}\right\}$	158.0	142.7	154.3	160.1
Mounting Height	.67D	.67D	.67D	.67D
D—Average spacing of outlets.				
Allowable variation in mounting height	±.1D	±.1D	±.1D	±.1D

CANDLE-POWER DISTRIBUTION CURVES FOR BOWL TYPE REFLECTORS



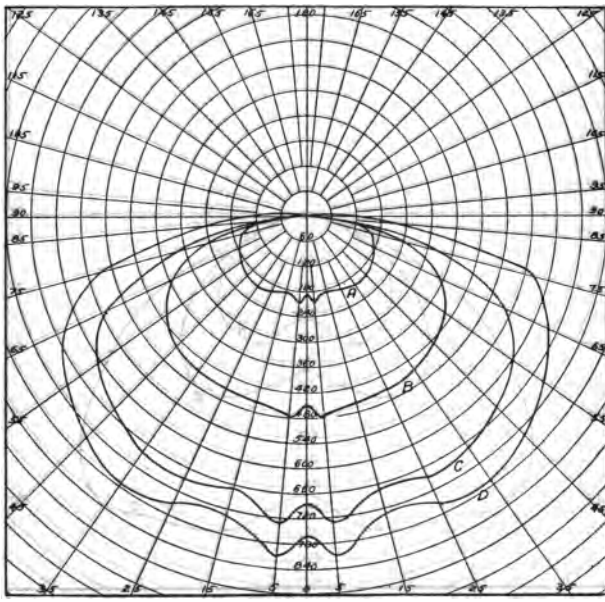
No. of Curve	A	B	C
Size of Lamp (Watts)	25	40	60
Size of Reflector (Inches dia.)	7″	7″	8″
Effective Lumens per Lamp	100	160.5	260
Efficiency of Reflector (%) $\left\{\frac{\text{MSCP (R)}}{\text{MSCP (L)}}\right\}$	52.1	52.5	58.8
Value as a Reflector (%) $\left\{\frac{\text{MLHCP (R)}}{\text{MLHCP (L)}}\right\}$	100.0	104.0	114.9
Mounting Height	.8D	.8D	.8D
D—Average spacing of outlets.			
Allowable variation in mounting height	±.1D	±.1D	±.1D

CANDLE-POWER DISTRIBUTION CURVES FOR BOWL TYPE REFLECTORS—(Continued)



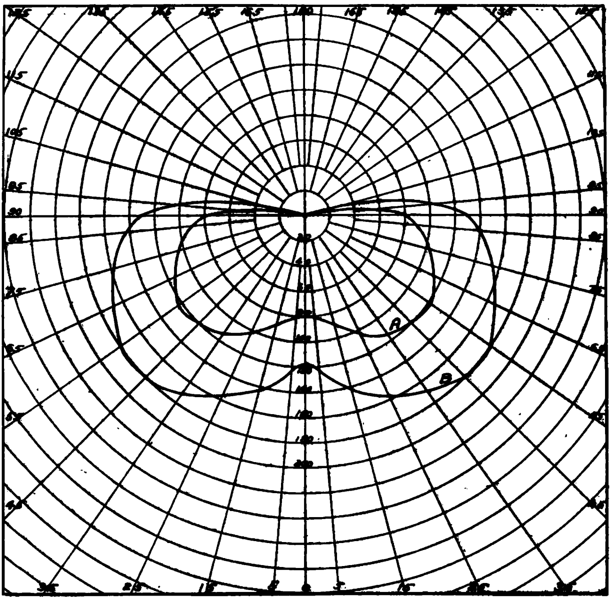
		A	B	C
No. of Curve		A	B	C
Size of Lamp (Watts)		[illegible]	[illegible]	[illegible]
Size of Reflector Opening dia.		[illegible]	[illegible]	[illegible]
Effective Lumens per Lamp		[illegible]	[illegible]	[illegible]
Efficiency of Reflector (%)	Max. [illegible] / Max. [illegible]	[illegible]	[illegible]	[illegible]
Value as a Reflector (%)	Max. [illegible] / Max. [illegible]	[illegible]	[illegible]	[illegible]
Mounting Height ÷ Average spacing of outlets		[illegible]	[illegible]	[illegible]
Allowable variation in mounting height		[illegible]	[illegible]	[illegible]

CANDLE-POWER DISTRIBUTION CURVES FOR DOME REFLECTORS



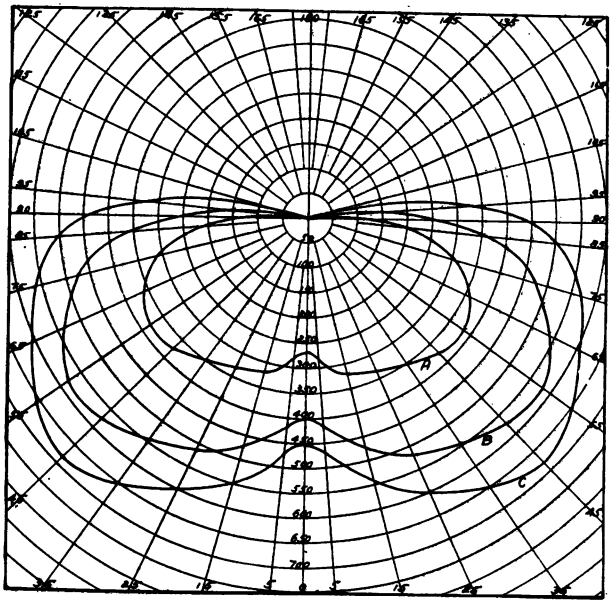
No. of Curve	A	B	C	D
Size of Lamp (Watts)	150	250	400	500
Size of Reflector (Inches dia.)	14″	18″	18″	18″
Effective Lumens per Lamp	605	1360	2020	2450
Efficiency of Reflector (%) $\left\{\frac{\text{MSCP (R)}}{\text{MSCP (L)}}\right\}$	82.4	81.5	73.7	74.0
Value as a Reflector (%) $\left\{\frac{\text{MLHCP (R)}}{\text{MLHCP (L)}}\right\}$	157.3	162.0	141.9	145.9
Mounting Height	.67D	.67D	.67D	.67D
D—Average spacing of outlets.				
Allowable variation in mounting height	±.1D	±.1D	±.1D	±.1D

CANDLE-POWER DISTRIBUTION CURVES FOR FLAT REFLECTORS



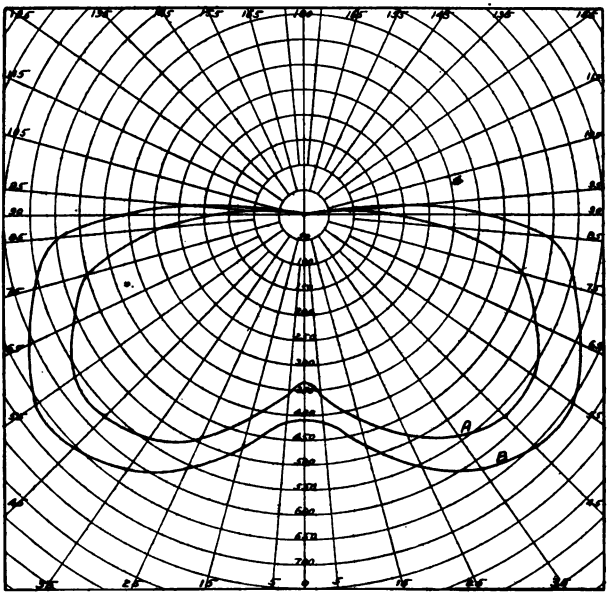
No. of Curve	A	B
Size of Lamp (Watts)	100	150
Size of Reflector (Inches dia.)	16″	16″
Effective Lumens per Lamp	349	530
Efficiency of Reflector (%) $\left\{\dfrac{\text{MSCP (R)}}{\text{MSCP (L)}}\right\}$	85.2	88.4
Value as a Reflector (%) $\left\{\dfrac{\text{MLHCP (R)}}{\text{MLHCP (L)}}\right\}$	155.0	151.0
Mounting Height	.67D	.67D
D—Average spacing of outlets.		
Allowable variation in mounting height	±.1D	±.1D

CANDLE-POWER DISTRIBUTION CURVES FOR FLAT REFLECTORS—(Continued)



No. of Curve	A	B	C
Size of Lamp (Watts)	250	400	500
Size of Reflector (Inches dia.)	20″	20″	20″
Effective Lumens per Lamp	1152	1750	2025
Efficiency of Reflector (%) $\left\{\frac{\text{MSCP (R)}}{\text{MSCP (L)}}\right\}$	89.0	83.1	83.8
Value as a Reflector (%) $\left\{\frac{\text{MLHCP (R)}}{\text{MLHCP (L)}}\right\}$	172.5	151.8	148.0
Mounting Height	.67D	.67D	.67D
D—Average spacing of outlets.			
Allowable variation in mounting height	±.1D	±.1D	±.1D

CANDLE-POWER DISTRIBUTION CURVES FOR FLAT REFLECTORS—(Continued)



No. of Curve	A	B
Size of Lamp (Watts)	400	500
Size of Reflector (Inches dia.)	22"	22"
Effective Lumens per Lamp	1670	1915
Efficiency of Reflector (%) $\left\{\frac{\text{MSCP (R)}}{\text{MSCP (L)}}\right\}$	74.4	76.9
Value as a Reflector (%) $\left\{\frac{\text{MLHCP (R)}}{\text{MLHCP (L)}}\right\}$	140.0	145.0
Mounting Height	.67D	.67D
D—Average spacing of outlets.		
Allowable variation in mounting height	±.1D	±.1D

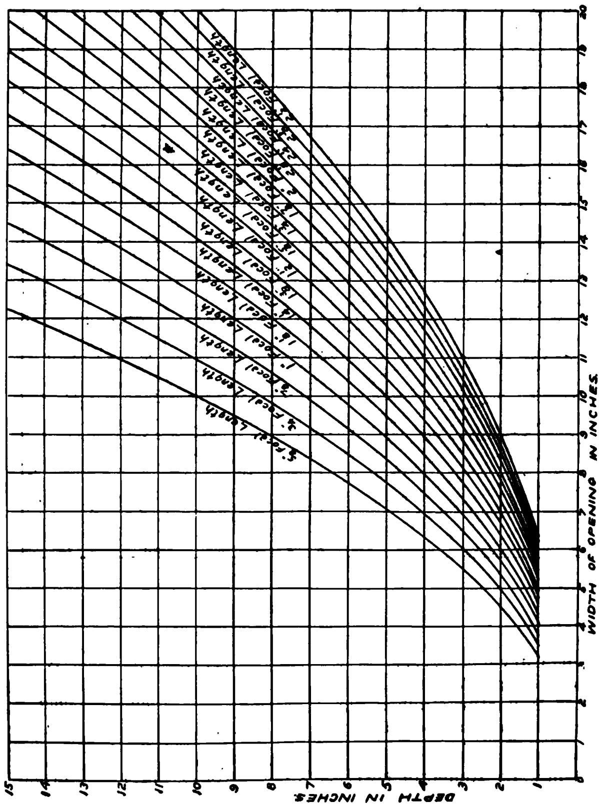


Fig. 12

PARABOLIC REFLECTORS

All reflectors for headlight service for use with a point source of light are designed with a parabolic cross-section. Theoretically all rays of light emanating from the focal point of a parabola are reflected from the surface of the parabola in straight lines, parallel to the axis of the parabola. This makes a reflector of parabolic design most efficient for reflecting light in a narrow intense beam.

Incandescent electric lamps for headlight service are made with a small source of light for use with parabolic reflectors. The distance from the edge of the base of the parabola next to the bulb to the center of the source of light is called the focal length of the lamp. The focal length of the reflector should bear such relation to the focal length of the lamps that by means of an adjustable socket the two can be made the same. This precludes the use of a reflector having a shorter focal length than the lamp, as the bulb will prevent the proper adjustment of the lamp for focusing.

The focal length of reflectors having true parabolic cross section can be obtained by the use of the formula:

$$y^2 = 4px$$

where $y =$ one-half the opening,
$x =$ depth from opening to rear of reflector,
$P =$ focal length.

The curves of Fig. 12 have been accurately drawn to facilitate the finding of the focal length. Measure the opening of the reflector in inches and its depth from the opening to the bottom of the reflector. For this purpose use a scale and straightedge. Lay the straightedge across the opening and measure perpendicular to it. Having these measurements, inspection of the table will determine the length.

SECTION VIII

ILLUMINATION OF PASSENGER EQUIPMENT AND STATIONS

CAR ILLUMINATION

The proper illumination of passenger equipment and railroad equipment in general has become a very important question with Railway Electrical Engineers. Manufacturers have supplied a much felt want in the way of accessories and information concerning good practice is becoming more and more standardized.

Baggage and Express Cars: In Fig. 1 is shown the cross section of a baggage car showing the center fixture which supports a 50 watt Mazda lamp with G-30 bulb. A substantial reflector for this use is the aluminum finish on steel or enamel steel, similar to that shown in Fig. 2. The distribution of light from the unit is of great importance also, as upon it depends the satisfaction received from the system.

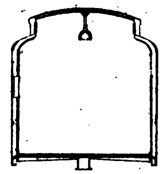


Fig. 1. Section of Baggage Car Showing Position of Lighting Unit

Fig. 2
HOLOPHANE-D'OLIER REFLECTOR No. 18470
(One-third Scale)

Fig. 3
HOLOPHANE-D'OLIER REFLECTOR No. 18460
(One-third Scale)

Postal Car Lighting: The proper directing and distribution of light in a postal car is very important. Shadows must be minimized and an intensity produced which will be ample for continued reading. Fig. 2 illustrates a reflector developed especially for this service which will prove a very satisfactory unit. The distribution curve of candlepower is shown in Fig. 4 on page 216.

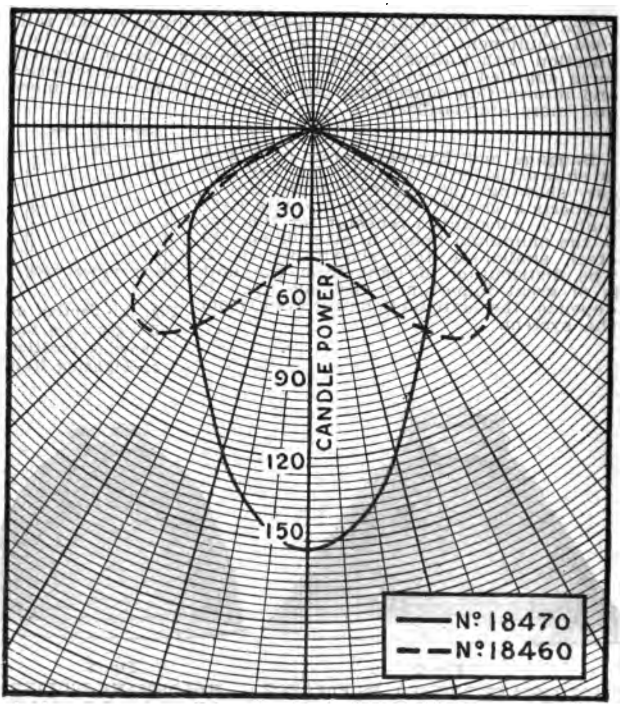


Fig. 4

Unit	*Lamp recommended*	*Position*
18470	50-watt, clear bulb, tungsten, train lighting	W
18460	50-watt, clear bulb, tungsten, train lighting	W

Candle-power distribution curve given by Reflector No. 18460.

The location of units depends upon the size and spacing.

Fig. 5. Baggage Car Equipment

Passenger or Day Coach: The illumination of passenger cars presents greater difficulties than are met with in ordinary problems, due to the peculiar construction and interior finish. The general form of the car makes it necessary to locate lamps (contrary to accepted rules of illuminating engineering) within the range of vision of the passengers.

At the present time numerous experiments are being conducted to standardize on a unit which eliminates objectionable glare and produces a pleasing form of lighting for day coaches. On page 218 is illustrated a number of designs which, with the proper distributing and diffusing glassware, lend themselves to coach lighting very harmoniously.

The following show the distribution curves on the above types of reflectors.

Fig. 7
HOLOPHANE REFLECTOR
No. 18226 S. F.
Shown with Fixture Made by John Williams, Inc. (1/6 Scale). Especially Designed for Day Coach Lighting

Fig. 8. Interior of Passenger Coach, Showing Lighting Units

Fig. 9
HOLOPHANE REFLECTOR FOR 18236 PLAIN EDGE
Shown with Fixture Made by Adams & Westlake Company (3/16 Scale) Especially Designed for Day Coach Lighting

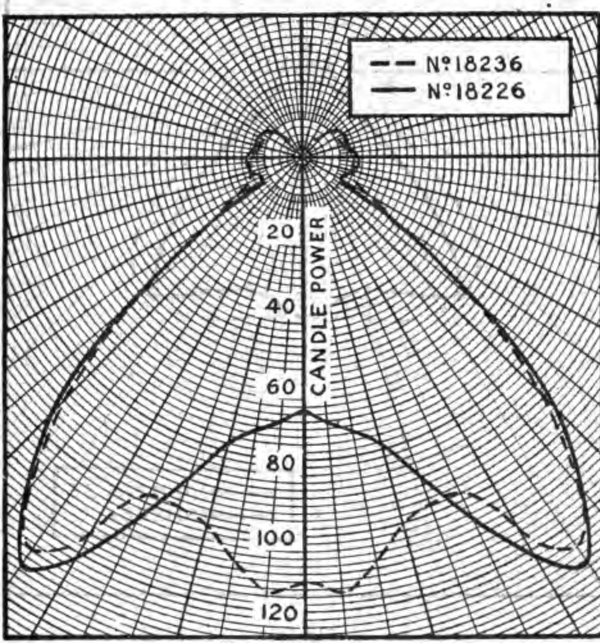


Fig. 6

Unit	*Lamp recommended*	*Position*
18226	50-watt, clear bulb, tungsten, train lighting	W
18236 plain edge	50-watt, clear bulb, tungsten, train lighting	Y

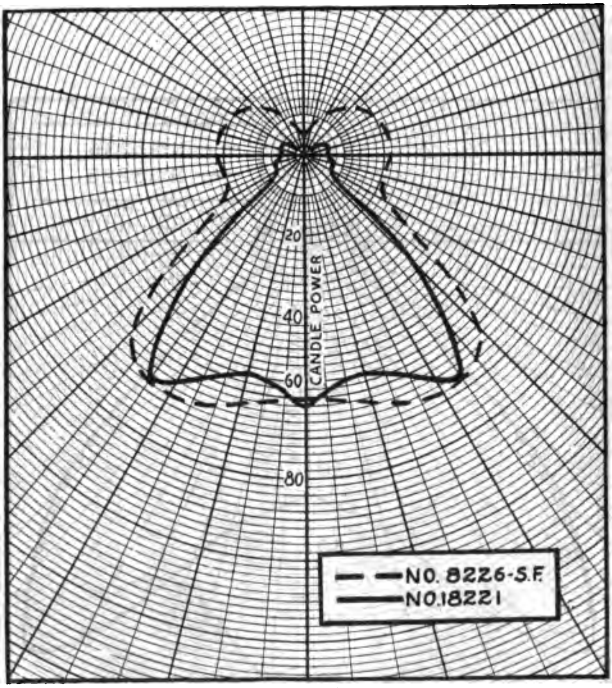


Fig. 10

Light Distribution Given by the No. 18221 and No. 18226 S. F. Reflectors

Unit	*Lamp recommended*	*Position*
18221	25-watt, clear bulb, train lighting tungsten	R
18226 S.F.	25-watt, clear bulb, train lighting tungsten	W

The two principal methods of arranging lamps as now followed by the majority of railroads are to adopt the center fixture scheme with either four candle-power lamps or one large 40 candle-power lamp; or to use what is known as the semi-concealed method. The first method has been most generally adopted and is shown in section in Fig. 11.

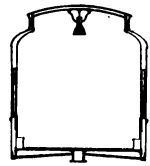


Fig. 11. Section of Passenger Coach Showing Location of Lighting Unit in Car.

The recommended intensities for the illumination of cars will be found in the table under the heading of Illumination and Photometry.

Dining Cars: In dining cars, in addition to the utilitarian, a little of the esthetic is looked for, consequently fixtures in cars of this nature are more ornamental. The lighting for this type of car has unquestionably been given more consideration than has any other type. However, the requirements are such that but very few of the methods have so far proven entirely satisfactory.

Fig. 12

Illustrations of other fixtures found of value in dining car lighting are show in Figs. 14 and 15. The distribution curves of these units have likewise been included.

Fig. 13

HOLOPHANE REFLECTOR PLATE UNIT No. 18371
Shown with Fixture Made by Safety Car H. & L. Company (2/5 Scale)

Fig. 14
HOLOPHANE REFLECTOR PLATE
UNIT No. 18371
(2/5 Scale)
Especially Designed for Dining Car
Lighting (Half Deck Service)

Fig. 15

HOLOPHANE-D'OLIER
REFLECTOR 18454
(1/3 Scale)

HOLOPHANE-D'OLIER
REFLECTOR 18540
(1/3 Scale)

Especially Designed for Dining Car, Kitchen and Pantry Lighting

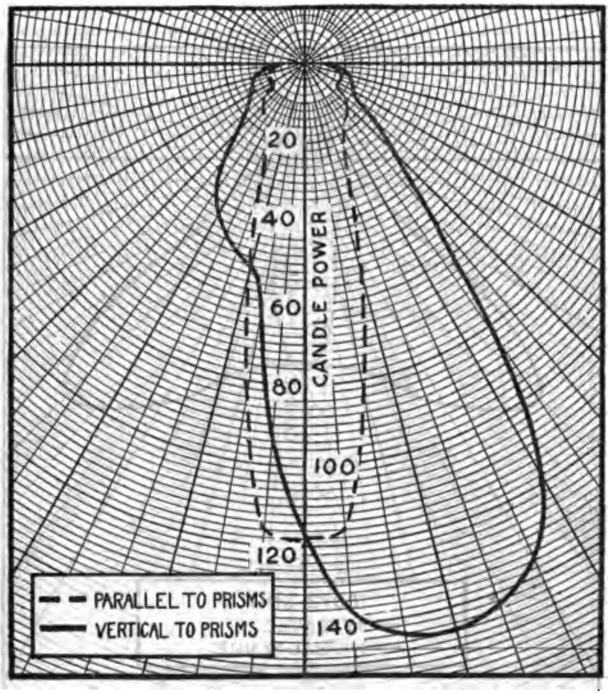


Fig. 16

Light Distribution Given by the No. 18371 Reflector Plate Unit

Unit	*Lamp recommended*	*Position*
18371	25-watt, clear bulb, tungsten, train lighting	¾ inch*

*Distance end contact of lamp above top of reflector.

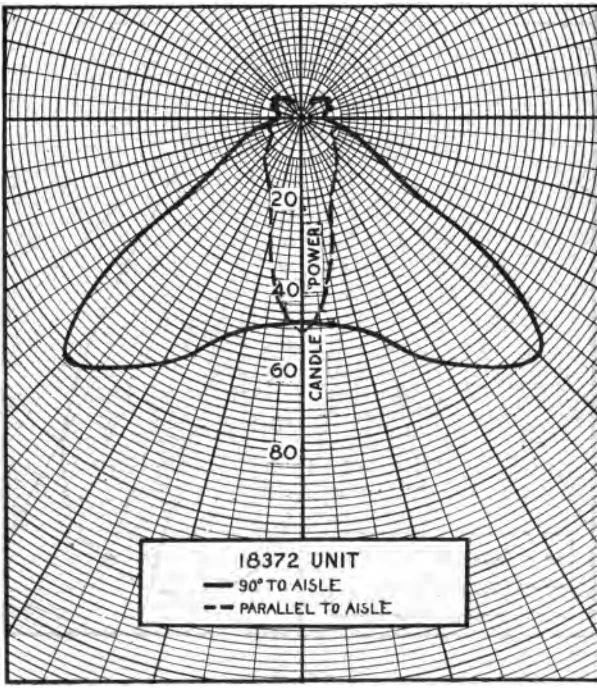


Fig. 17

Light Distribution Given by the No. 18372 Unit

Unit	*Lamp recommended*	*Position*
18372	**25-watt, clear bulb, train lighting**	**¾ inch***

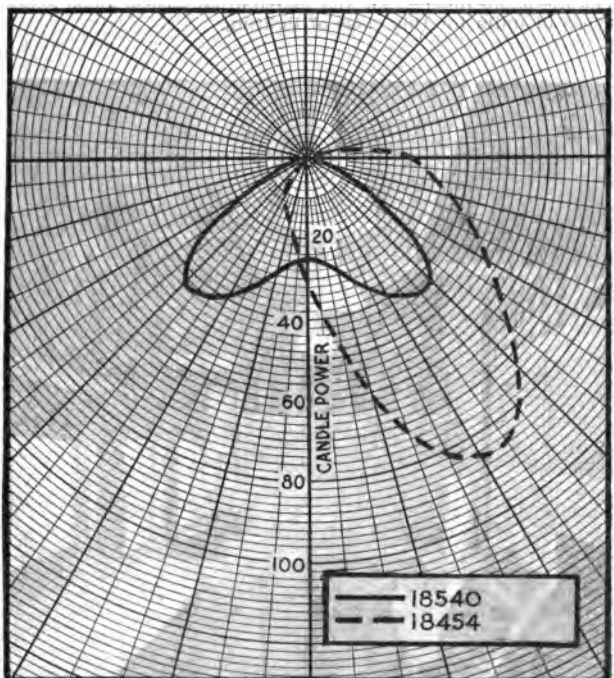


Fig. 19

Light Distribution Given by No. 18540 and No. 18454 Reflectors

Unit	*Lamp recommended*	*Position*
18540	15-watt, or 25-watt, clear bulb, train lighting, tungsten	R
18454	15-watt, or 25-watt, clear bulb, train lighting, tungsten	R

The lighting of the kitchen and pantry on dining cars is of importance as it affects naturally the service that can be rendered. Glass or steel is adaptable to this class of lighting choice being greatly a matter of personal like or dislike. The foregoing illustration and distribution curves show some types of units for this class of lighting.

Fig. 18

Parlor Cars: Here, too, the lighting scheme should lend itself to artistic treatment. A pleasant adequate light should be produced which is devoid of sharp shadows.

Fig. 20

The half deck and ceiling deck light are both used, the combination of the two being the more common.

Fig. 21
HOLOPHANE UNIT No. 18310
Shown with Fixture Made by Pullman Company
(1/4 Scale)
Especially Designed for Sleeping Car and Parlor Car Lighting

Fig. 22
HOLOPHANE UNIT
No. 18305
Shown with Fixture Made by Pullman Company
(1/4 Scale)

Fig. 23
HOLOPHANE PLATFORM LIGHTING UNIT No. 59922
(1/4 Scale)

Fig. 24
HOLOPHANE PLATFORM LIGHTING UNIT No. 56134
(1/4 Scale)
Especially Designed for Platform Lighting

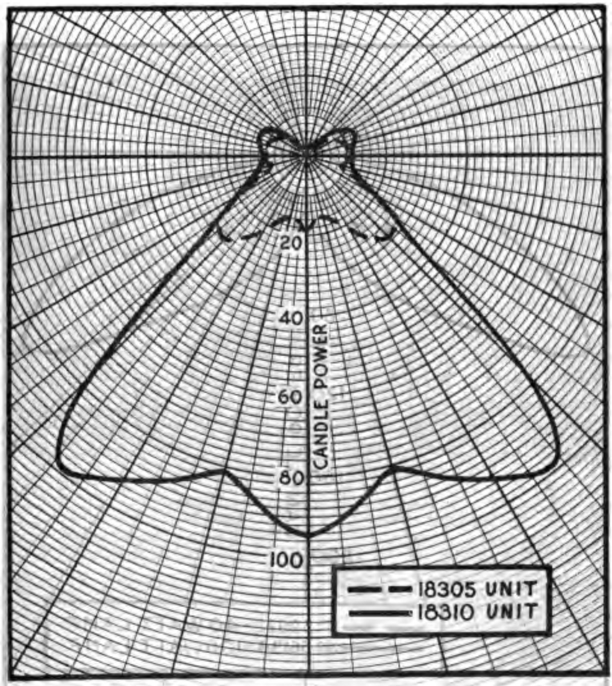


Fig. 25

Light Distributions Given by the No. 18305 and No. 18310 Units

Unit	*Lamp recommended*	*Position*
18305	15-watt or 25-watt, clear bulb, train lighting tungsten	R
18310	50-watt, clear bulb, train lighting tungsten	Y

The above fixtures are but indicative of many pleasing and efficient designs for car lighting.

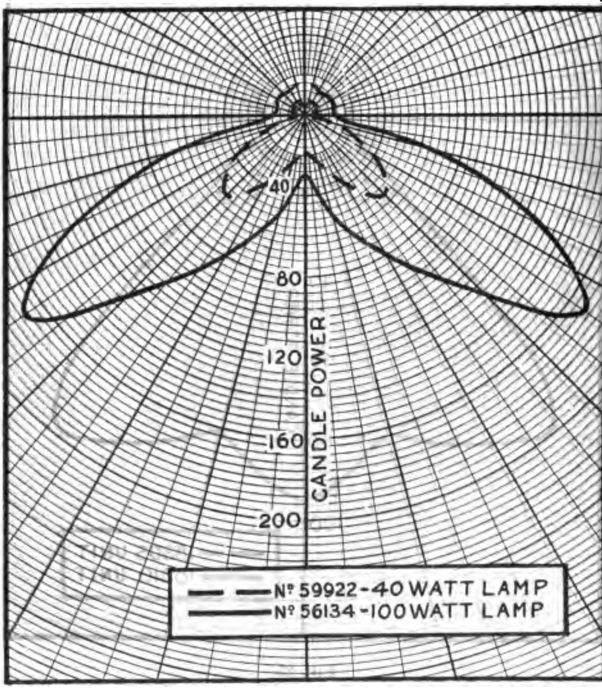


Fig. 28

Light Distribution Given by the No. 59922 and No. 56134 Units

Unit	Lamp recommended	Position
59922	25-watt, clear bulb, 110-volt, tungsten	¼ in. below*
	40-watt, clear bulb, 110-volt, tungsten	¼ in. below*
56134	60-watt, clear bulb, 110-volt, tungsten	0 inch*
	100-watt, clear bulb, 110-volt, tungsten	0 inch*

*Distance end contact of lamp to top of reflector.

Fig. 26

Sleeping, Buffet, Parlor and Club cars come all under somewhat the same head. Something out of the ordinary is desired and yet the harmony of the whole car and the efficiency must not suffer.

Fig. 27

Platform and Station Lighting: This branch of railway lighting is as vital a factor to be considered for proper lighting as any branch heretofore mentioned. On platforms a light is desired, while being fairly wide in distribution, must at the same time be shielded from the eyes of approaching engineers. Serious accidents have happened from bright lights in the direct field of vision destroying a clear view of objects ahead.

A pleasing waiting room helps greatly to dispel the long minutes between trains. A waiting room properly lighted will permit of reading at any place in it and likewise combines the artistic in just the right proportion.

Fig. 29

HOLOPHANE REALITE UNIT No. 18812

(1/10 Scale)

Especially Suitable for Station Waiting Room Lighting

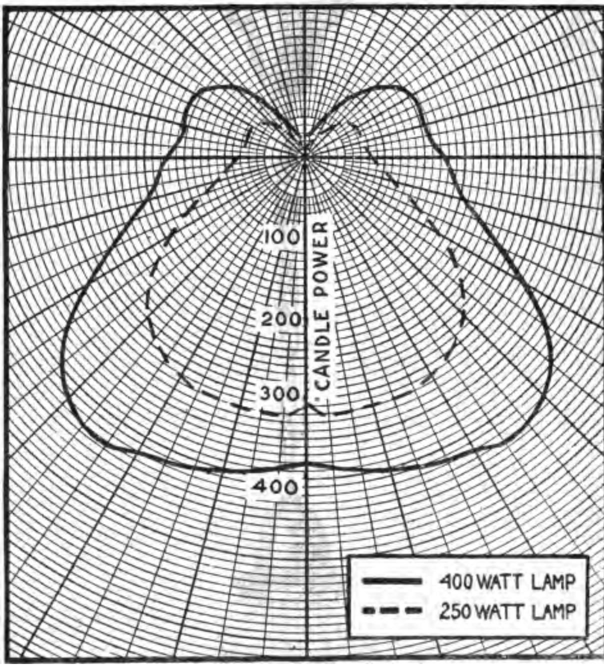


Fig. 30

No. 18312 Realite Unit

Unit	*Lamp recommended*	*Position*
18312	250-watt, clear bulb, tungsten, 100-volt 400-watt, clear bulb, tungsten, 110-volt	1⅝ inch* 2 inch*

*Distance end contact of lamp above top of reflector.

SECTION IX

WIRE

INCLUDING GAUGES, WEATHER-PROOF WIRE, RUBBER COVERED WIRE, MAGNET WIRE, CARRYING CAPACITY, RESISTANCE, INSULATORS, MELTING POINTS AND CONDUCTIVITIES OF ALLOYS, CURRENT REQUIRED TO FUSE WIRE, RUBBER INSULATION, WIRING TABLES, WIRING FORMULAE, METHODS OF MEASURING VOLTAGE, CURRENT, AND RESISTANCE

CONDUIT

SIZE AND SPECIFICATIONS

CLASSIFICATION OF GAUGES

In addition to the confusion caused by a multiplicity of wire gauges, several of them are known by various names. For example:

Brown and Sharpe (B. & S.) = American Wire Gauge (A. W. G.)

New British Standard (N. B. S.) = British Imperial, English Legal Standard Wire Gauge and is variously abbreviated as S. W. G. and I. W. G.

Birmingham Gauge (B. W. G.) = Stubs Old English Standard and Iron Wire Gauge.

Roebling = Washburn Moen, American Steel & Wire Co.'s Iron Wire Gauge.

London = Old English (not Old English Stnd.)

As a further complication:

Birmingham or Stubs Iron Wire Gauge is not the same as Stubs Steel Wire Gauge.

BROWN & SHARPE'S GAUGE

Brown and Sharpe's gauge, or as it is commonly known, the B. & S. gauge, is standard for copper wire. It is understood to apply in all cases where the size of copper wire is mentioned by its wire gauge number.

Reference to the following tables will show that for all practical purposes the area in circular mils is doubled for every third size heavier by gauge number and halved for every third size lighter by gauge number.

Every tenth size larger by gauge number has ten times the area in curcular mils. No. 10 B. & S. gauge has an area of approximately 10,000 circular mils, and from this basis the other sizes can be figured, if a table should not be handy.

GENERAL USES OF GAUGES

B. & S.—All forms of round wire used for electrical conductors. Sheet copper, Brass and German silver.

U. S. S. G.—Sheet iron and steel. Legalized by act of Congress, March 3, 1893.

B. W. G.—Galvanized iron wire. Norway iron wire.

American Screw Co.'s Wire Gauge.—Numbered sizes of machine and wood screws, particularly up to No. 14 (.2421 inch).

Stubs Steel Wire Gauge.—Drill rod.

Roebling & Trenton—Iron and steel wire. Telephone and telegraph wire.

N. B. S.—Hard drawn copper. Telephone and telegraph wire.

London Gauge—Brass wire.

EQUIVALENTS OF WIRES: B. & S. GAUGE

0000	= 2-0	= 4-3	= 8-6	= 16-9	= 32-12	= 64-15
000	= 2-1	= 4-4	= 8-7	= 16-10	= 32-13	= 64-16
00	= 2-2	= 4-5	= 8-8	= 16-11	= 32-14	= 64-17
0	= 2-3	= 4-6	= 8-9	= 16-12	= 32-15	.....
1	= 2-4	= 4-7	= 8-10	= 16-13	= 32-16	.....
2	= 2-5	= 4-8	= 8-11	= 16-14	= 32-17	.....
3	= 2-6	= 4-9	= 8-12	= 16-15	= 32-18	.....
4	= 2-7	= 4-10	= 8-13	= 16-16	.....	.....
5	= 2-8	= 4-11	= 8-14	= 16-17	.....	.....
6	= 2-9	= 4-12	= 8-15	= 16-18	.....	.....
7	= 2-10	= 4-13	= 8-16	.....	.....	.....
8	= 2-11	= 4-14	= 8-17	.....	.....	.....
9	= 2-12	= 4-15	= 8-18	.....	.....	.....
10	= 2-13	= 4-16	....	.....	.....	.....
11	= 2-14	= 4-17	....	.....	.....	.....
12	= 2-15	= 4-18	....	.....	.....	.....
13	= 2-16	= 4-19	....	.....	.....	.....
14	= 2-17	....	....	.....	.....	.....
15	= 2-18	....	....	.....	.....	.....
16	= 2-19	....	....	.....	.....	.....

WIRE DATA

Weatherproof Wires—Solid Conductors

Size B. & S.	Weatherproof Wire: Weight per 1,000 Feet	Weatherproof Wire: Weight per Mile	Weatherproof Wire: Diameter Over All	Slow Burning Weatherproof Wire: Weight per 1,000 Feet	Slow Burning Weatherproof Wire: Weight per Mile	Slow Burning Weatherproof Wire: Diameter Over All	Slow Burning Wire: Weight per 1,000 Feet	Slow Burning Wire: Weight per Mile	Slow Burning Wire: Diameter Over All
0000	767	4050	25/32	862	4550	3/4	925	4890	3/4
000	630	3220	47/64	710	3750	45/64	760	4020	45/64
00	502	2650	39/64	562	2970	37/64	600	3170	37/64
0	407	2150	9/16	462	2140	17/32	495	2610	17/32
1	316	1670	1/2	340	1800	15/32	365	1930	15/32
2	260	1370	15/32	280	1480	7/16	320	1690	7/16
3	200	1050	27/64	230	1220	13/32	270	1425	13/32
4	164	865	25/64	190	1000	3/8	220	1160	3/8
5	134	710	11/32	155	820	11/32	190	1000	11/32
6	112	590	5/16	127	670	5/16	160	845	5/16
8	75	395	17/64	85	450	17/64	100	530	17/64
10	53	280	1/4	60	315	1/4	80	420	1/4
12	35	185	7/32	42	220	7/32	55	290	7/32
14	25	130	3/16	30	160	3/16	40	210	3/16
16	14	75	5/32	15	80	5/32	18	95	5/32
18	11	58	1/8	12	63	1/8	14	75	1/8

WIRE DATA—Continued

Stranded Conductors

Size B. & S.	Weatherproof Wire			Slow Burning Weatherproof Wire			Slow Burning Wire		
	Weight per 1,000 Ft.	Weight per Mile	Diameter Over All	Weight per 1,000 Feet	Weight per Mile	Diameter Over All	Weight per 1,000 Feet	Weight per Mile	Diameter Over All
2000000 C.M.	7000	37000	2⅛	7300	38500	2	7800	41000	2
1750000 C.M.	6200	32750	2	6550	34600	1⅞	6900	36300	1⅞
1500000 C.M.	5400	28500	1⅞	5675	30000	1¾	6000	31300	1¾
1250000 C.M.	4500	23800	1¾	4780	25200	1 11/16	5000	26400	1 11/16
1000000 C.M.	3675	19400	1 21/32	3860	20400	1 39/64	3980	21000	1 39/64
900000 C.M.	3330	17600	1 39/64	3520	18600	1 9/16	3640	19200	1 9/16
800000 C.M.	3000	15800	1 9/16	3180	16800	1 33/64	3280	17300	1 33/64
700000 C.M.	2650	14000	1 15/32	2820	14900	1 27/64	2920	15400	1 27/64
600000 C.M.	2235	11800	1 21/64	2350	12400	1 9/32	2460	13000	1 9/32
500000 C.M.	1900	10000	1¼	1990	10500	1 13/64	2080	11000	1 13/64
450000 C.M.	1725	9100	1 3/16	1820	9600	1 9/64	1900	10000	1 9/64
400000 C.M.	1550	8200	1 9/64	1650	8700	1 3/32	1700	9000	1 3/32
350000 C.M.	1345	7100	1	1440	7600	31/32	1500	7900	31/32
300000 C.M.	1175	6200	31/32	1270	6700	15/16	1310	6900	15/16
250000 C.M.	985	5200	29/32	1060	5600	⅞	1120	5900	⅞
0000	800	4220	55/64	900	4750	53/64	940	5070	53/64
000	653	3450	51/64	735	3880	49/64	785	4150	49/64
00	522	2760	43/64	583	3080	41/64	625	3300	41/64
0	424	2240	39/64	480	2530	37/64	510	2700	37/64
1	328	1735	35/64	355	1870	33/64	380	2000	33/64
2	270	1425	33/64	290	1540	31/64	335	1770	31/64
3	206	1090	15/32	240	1270	29/64	280	1480	29/64
4	170	900	7/16	195	1030	27/64	230	1220	27/64
5	140	740	⅜	160	845	⅜	195	1030	⅜
6	115	610	11/32	132	695	11/32	165	870	11/32
8	78	410	9/32	87	460	9/32	105	555	9/32

WIRE DATA—Continued
Rubber Covered Wire—Solid Conductors

Size B. & S.	Diameter of Conductors Mils.	Cross Section Circular Mils.	Single Braid		Double Braid	
			Diameter Over All	Weight per 1,000 Feet	Diameter Over All	Weight per 1,000 Feet
0000	460	211600	$\frac{47}{64}$	809	$\frac{55}{64}$	832
000	410	167803	$\frac{11}{16}$	666	$\frac{13}{16}$	690
00	365	133079	$\frac{5}{8}$	546	$\frac{47}{64}$	568
0	325	105524	$\frac{19}{32}$	453	$\frac{45}{64}$	476
1	289	83695	$\frac{33}{64}$	355	$\frac{5}{8}$	376
2	258	66373	$\frac{29}{64}$	275	$\frac{9}{16}$	295
3	230	52634	$\frac{27}{64}$	227	$\frac{33}{64}$	245
4	204	41743	$\frac{25}{64}$	186	$\frac{15}{32}$	200
5	182	33102	$\frac{23}{64}$	160	$\frac{7}{16}$	170
6	162	26250	$\frac{5}{16}$	128	$\frac{25}{64}$	135
8	129	16510	$\frac{17}{64}$	80	$\frac{11}{32}$	86
10	102	10382	$\frac{15}{64}$	58	$\frac{19}{64}$	64
12	81	6530	$\frac{7}{32}$	43	$\frac{9}{32}$	48
14	64	4107	$\frac{13}{64}$	32	$\frac{1}{4}$	37
16	51	2583	$\frac{3}{16}$	20	..	...
18	40	1624	$\frac{11}{64}$	16	..	...
19	36	1288	$\frac{5}{32}$	15	..	...
20	32	1022	$\frac{9}{64}$	14	..	...

WIRE DATA—Continued

Rubber Covered Wire—Stranded Conductors

Size B. & S.	Concentric Strands		Diameter of Conductors Mils.	Single Braid		Double Braid	
	No. Wires	Diameter Each. Mils.		Diameter Over All	Weight per 1,000 Feet	Diameter Over All	Weight per 1,000 Feet
2000000 C.M.	91	148	1650	2	7246	2 9/64	7385
1750000 C.M.	91	139	1550	1 29/32	6394	2 3/64	6525
1500000 C.M.	91	128	1430	1 51/64	5539	1 15/16	5658
1250000 C.M.	91	117	1308	1 43/64	4678	1 13/16	4783
1000000 C.M.	61	128	1166	1 1/2	3754	1 5/8	3849
900000 C.M.	61	121	1104	1 7/16	3404	1 9/16	3491
800000 C.M.	61	115	1049	1 3/8	3058	1 1/2	3138
750000 C.M.	61	111	1013	1 11/32	2881	1 15/32	2956
700000 C.M.	61	107	978	1 5/16	2709	1 7/16	2880
650000 C.M.	61	103	943	1 17/64	2534	1 25/64	2600
600000 C.M.	61	99	906	1 1/4	2355	1 3/8	2418
550000 C.M.	61	95	870	1 13/64	2182	1 21/64	2240
500000 C.M.	37	116	821	1 1/8	1959	1 1/4	2010
450000 C.M.	37	110	779	1 3/32	1791	1 7/32	1840
400000 C.M.	37	104	738	1 3/64	1608	1 11/64	1650
350000 C.M.	37	97	688	1	1431	1 1/8	1468
300000 C.M.	37	90	639	15/16	1250	1 1/16	1285
250000 C.M.	37	82	583	7/8	1071	1	1103
0000	19	105	530	13/16	899	15/16	942
000	19	94	475	3/4	740	7/8	782
00	19	83	425	45/64	607	13/16	647
0	19	74	380	5/8	492	47/64	526
1	19	66	329	9/16	387	43/64	417

WIRE DATA—Continued

Rubber Covered Wire—Stranded Conductors

Size B. & S.	Concentric Strands: No. Wires	Concentric Strands: Diameter Each, Mils	Diameter of Conductors Mils	Single Braid: Diameter Over All	Single Braid: Weight per 1,000 Feet	Double Braid: Diameter Over All	Double Braid: Weight per 1,000 Feet
2	19	59	296	½	303	39/64	329
3	7	86	263	29/64	249	9/16	272
4	7	77	233	7/16	204	17/32	227
5	7	68	209	13/32	175	½	192
6	7	61	185	⅜	141	29/64	156
8	7	48	147	21/64	90	13/32	103
10	7	39	118	19/64	65	⅜	72
12	7	31	94	17/64	48	21/64	55
14	7	24	75	15/64	36	19/64	40

Rubber Covered Duplex

Size B. & S.	Solid: Diameter Over All	Solid: Weight per 1,000 Feet	Stranded: Diameter Over All	Stranded: Weight per 1,000 Feet
1	..	...	1¼	810
2	..	...	1⅛	638
3	..	...	1 1/32	528
4	..	...	31/32	442
5	..	...	29/32	375
6	..	...	53/64	307
8	11/16	170	43/64	203
10	37/64	125	⅝	143
12	½	94	9/16	107
14	27/64	73	15/32	78

All weights are approximate but are exact enough for all practical purposes.

WIRING TABLES

Table of Carrying Capacity of Wires

Below is a table showing the allowable carrying capacity of wires containing 98 per cent pure copper, which must be followed in placing interior conductors:

RUBBER COVERED WIRES

B. & S. Gauge	Amperes	Circular Mils.	Amperes
18	3	200,000	200
16	6	300,000	270
14	12	400,000	330
12	17	500,000	390
10	24	600,000	450
8	33	700,000	500
6	46	800,000	550
5	54	900,000	600
4	65	1,000,000	650
3	76	1,100,000	690
2	90	1,200,000	730
1	107	1,300,000	770
0	127	1,400,000	810
00	150	1,500,000	850
000	177	1,600,000	890
0000	210	1,700,000	930
		1,800,000	970
		1,900,000	1,010
		2,000,000	1,050

The low limit is specified for rubber covered wires to prevent gradual deterioration of the high insulations by the heat of the wires, but not from fear of igniting the insulation. The question of drop is not taken into consideration in the above tables.

FINE MAGNET WIRE

No. B. & S. Gauge	Diameter	Ohms, per Pound		Feet, per Pound	
		Single Cotton	Double Cotton	Single Cotton	Double Cotton
20	.0319	3.15	3.02	311	298
21	.0284	4.97	4.72	389	370
22	.0253	7.87	7.44	491	461
23	.0225	12.45	11.7	624	584
24	.0201	19.65	18.25	778	745
25	.0179	30.9	28.45	958	903
26	.0159	48.5	44.3	1188	1118
27	.0142	76.5	68.8	1533	1422
28	.0126	120.	106.5	1908	1759
29	.0112	190.5	164.	2461	2207
30	.0100	294.5	252.	2893	2534
31	.0089	461.	384.5	3483	2768
32	.0079	717.	585.	4414	3737
33	.0070	1115.	880.	5688	4697
34	.0063	1715.	1315.	6400	6168
35	.0056	2640.	1960.	8393	6737
36	.005	4070.	2890.	9846	7877
37	.0044	6180.	4230.	11636	9309
38	.0039	9430.	6150.	13848	10666
39	.0035	14200.	8850.	18286	11907
40	.0031	21300.	12500.	24381	14222

TABLE OF DIMENSIONS, WEIGHTS AND RESISTANCES OF PURE COPPER WIRE

Based on Dr. Matthiesen's Standard of Conductivity

B. & S. Gauge	Diameter Inches	Area		Weight	Length		Resistance at 75° F.	
		Circular Mils	Square Mils	Pounds per 1,000 Ft.	Feet per Pound	Feet per Ohm	Ohms per 1,000 Ft.	Ohms per Pound
0000	.460000	211600.00	166190.0	639.33	1.56	20383.0	.04906	.000076736
000	.409640	167805.00	131790.0	507.01	1.97	16165.0	.06186	.00012039
00	.364800	133079.40	104520.0	402.09	2.49	12820.0	.07801	.00019423
0	.324860	105538.00	82887.0	318.86	3.14	10166.0	.09838	.00038500
1	.289300	83694.20	65733.0	252.88	3.95	8062.3	.12404	.00048994
2	.257630	66373.00	52130.0	200.54	4.99	6393.7	.15640	.00078045
3	.229420	52634.00	41339.0	159.03	6.29	5070.2	.19723	.0012406
4	.204310	41742.00	32784.0	126.12	7.93	4021.0	.24869	.0019721
5	.181940	33102.00	25998.0	100.01	10.00	3188.7	.31361	.0031361
6	.162020	26250.50	20617.0	79.32	12.61	2528.7	.39546	.0049868
7	.144280	20816.00	16349.0	62.90	15.90	2005.2	.49871	.0079294
8	.128490	16509.00	12966.0	49.88	20.05	1590.3	.62881	.012608
9	.114430	13094.00	10284.0	39.56	25.28	1261.3	.79281	.020042
10	.101890	10381.00	8153.2	31.37	31.38	1000.0	1.0000	.031380
11	.090742	8234.00	6467.0	24.88	40.20	793.18	1.2607	.050682
12	.080808	6529.90	5128.6	19.73	50.69	629.02	1.5898	.080585
13	.071961	5178.40	4067.1	15.65	63.91	498.83	2.0047	.12841
14	.064048	4106.70	3225.4	12.44	80.38	395.60	2.5278	.20322
15	.057068	3256.7	2557.8	9.84	101.63	321.02	3.1150	.31658
16	.050820	2582.9	2028.6	7.81	128.14	248.81	4.0191	.51501
17	.045257	2048.2	1608.6	6.19	161.59	197.30	5.0683	.81900
18	.040303	1624.3	1275.7	4.91	203.76	156.47	6.3911	1.3023

Data on Solid Wires Larger than 4/0

No. B. & S. Gauge	Diameter Mils.	Circular Mils.	Feet, per Pound	Pounds per Foot	Ohms per Mile
5/0	515	265,225	1.29	.80	.206
6/0	575	330,625	1.00	1.00	.165
7/0	640	409,600	.81	1.24	.133
8/0	710	504,100	.66	1.53	.108
9/0	785	616,225	.54	1.86	.089
10/0	865	748,225	.44	2.25	.073
11/0	950	902,500	.37	2.73	.060
12/0	1040	1,081,600	.21	3.27	.050

INSULATORS IN ORDER OF THEIR VALUE

Dry air	Jet	Silk
Shellac	Glass	Dry paper
Paraffin	Mica	Parchment
Amber	Ebonite	Dry leather
Resins	Gutta-percha	Porcelain
Sulphur	India-rubber	Oils
Wax		

MELTING POINT AND RELATIVE ELECTRICAL CONDUCTIVITY OF DIFFERENT METALS AND ALLOYS

Metals	Relative Conductivity	Melting Point ° F.
Pure silver	100.	1873
Pure copper	100.	2550
Refined and crystallized copper	99.9	....
Telegraphic silicious bronze	98.	....
Alloy of copper and silver (50%)	86.65	....
Pure gold	78.	2016
Silicide of copper, 4% Si	75.	....
Silicide of copper, 12% Si	54.7	....
Pure aluminum	54.2	1160
Tin with 12% of sodium	46.9	....
Telephonic silicious bronze	35.	....
Copper with 10% of lead	30.	....
Pure zinc	29.9	773
Telephonic phosphor-bronze	29.	....
Silicious brass, 25% zinc	26.49	....
Brass with 35% zinc	21.5	....
Phosphor tin	17.7	....
Alloy of gold and silver (50%)	16.12	....
Swedish iron	16.	4000
Pure Banca tin	15.45	442
Antimonial copper	12.7	....
Aluminum bronze (10%)	12.6	....
Siemens steel	12.	....
Pure platinum	10.6	4100
Copper with 10% of nickel	10.6	....
Cadmium amalgam (15%)	10.2	....
Dronier mercurial bronze	10.14	....
Arsenical copper (10%)	9.1	....
Pure lead	8.88	630
Bronze with 20% of tin	8.4	....
Pure nickel	7.89	2800
Phosphor-bronze, 10% tin	6.5	....
Phosphor-copper, 9% phosphorus	4.9	....
Antimony	3.88	840

CURRENT REQUIRED TO FUSE WIRES OF COPPER, GERMAN SILVER AND IRON

B. & S. Gauge	Copper Amperes	German Silver Amperes	Iron Amperes
10	333.	169.	101.
11	284.	146.	86.
12	235.	120.7	71.2
13	200.	102.6	63.
14	166.	85.2	50.2
15	139.	71.2	42.1
16	117.	60.	35.5
17	99.	50.4	32.6
18	82.8	42.5	25.1
19	66.7	34.2	20.2
20	58.8	29.9	17.7
21	49.3	25.3	14.9
22	41.2	21.1	12.5
23	34.5	17.7	10.9
24	28.9	14.8	8.76
25	24.6	12.6	7.46
26	20.6	10.6	6.22
27	17.7	9.1	5.26
28	14.7	7.5	4.45
29	12.5	6.41	3.79
30	10.25	5.26	3.11
31	8.75	4.49	2.65
32	7.26	3.73	2.2
33	6.19	3.18	1.88
34	5.12	2.64	1.55
35	4.37	2.24	1.33
36	3.62	1.86	1.09
37	3.08	1.58	.93
38	2.55	1.31	.77
39	2.20	1.13	.67
40	1.86	.95	.56

RUBBER COVERED WIRE

Too much stress cannot be laid on the importance of properly wiring the car. While no two railroads follow the same methods in wiring the different classes of cars, there are several general rules that should be rigidly followed.

All wiring should be in iron pipe conduit, and as near watertight as it is possible to make it. Whenever taps or connections are made junction boxes should be used, so located that in case of a short circuit or ground the replacement of a wire would be an easy matter.

Only rubber covered wire should be used. This does not mean the ordinary code wire. Some engineers appear to think that all wire is satisfactory if it conforms to the National Code or Board of Fire Underwriter's Rules. They will examine carefully all the other features of the lighting system but will pass carelessly over the question of wire, apparently considering all wires alike. They labor under the mistaken assumption that the common identity of copper establishes a relationship of equality.

The wiring is just as important as any other detail and badly insulated wire is not only a menace but a peril to the success of any lighting system. The wires should be properly tested and installed and the insulation must be perfect.

Much wire passes under the misleading name of "Rubber Covered" when, as a matter of fact, there is not one ounce of rubber in its composition. It is composed of rubber substitutes and cheap ingredients, and as one writer aptly states, bears as much relation to pure rubber as a burnt cinder to a lump of coal. Such insulation falls an easy prey to temperature variations and climatic conditions and soon disintegrates, as, having no rubber, it possesses no vitality, no dialectric strength and no capacity for work. Consequently it is entirely worthless and should under no conditions be used. The fault lies, not with the manufacturers, but with the rules which require a certain thickness of insulation and do not specify whether this insulation shall be composed of clay or rubber.

On the other hand, rubber by itself is worthless as an insulating material for the reason that in its natural condition it absorbs more or less moisture and when exposed to the air rapidly oxidizes. This naturally precludes its use for insulating material, but, in conjunction with the proper ingredients and when properly vulcanized, it becomes not only waterproof but almost indestructible under normal conditions.

Vulcanization, when properly done, does not alter the constitution of rubber but it can be made to adversely affect or deceptively modify its behavior. When over-vulcanized it becomes hard and brittle, and when under-vulcanized it becomes flabby and inert. In the one case, under a tensile test, the insulation will break and in the other it will stretch but not recover.

Good insulation is indicated by its ability to withstand a tensile test of 800 lbs. per square inch without exceeding its elastic limit. This test can be approximated by stretching the insulation several times to three or four times its original length. While the insulation may be considered satisfactory, if it recovers and jumps back to its original form with a vigor similar to a magnetic pull after the elongation test, nevertheless the tensile test outlined above is much preferable in weeding out the cheaper grades of rubber.

This tensile test is easily obtained where there is 30 per cent Fine Para in the insulation. It can also be satisfactorily fulfilled where there is a less amount of Para and from 40 to 50 per cent of a cheaper grade of rubber. This is, of course, a serious drawback where the best results are desired. The test, however, if it does not assure the best, nevertheless wipes out the cheaper substitute and assures an insulation that if not equal in durability to 30 per cent of Para is immeasurably superior to anything that can be obtained short of a chemical analysis.

WIRING FORMULÆ

Ohm's Law: The Electrical Units—volt, ohm and ampere—which are most frequently used, have fortunately been established so as to bear simple but important relations to one another, based upon the current increasing and decreasing with the voltage, but increasing when the resistance decreases, and decreasing when the resistance increases.

Using the symbols mentioned above, this is expressed in the following equations:

$$I = \frac{E}{R} \quad E = IR \quad R = \frac{E}{I} \quad EI \text{ (or watts)} = I^2R$$

$$EI \text{ (or watts)} = \frac{E^2}{R}$$

Kirchhoff's Laws: Kirchhoff's Laws, of which there are two, are of especial value in dealing with a network of conductors.

First Law: The algebraic sum of all the currents at any point is equal to zero.

From Fig. 1

$$+I - i_1 - i_2 - i_3 = 0$$

or

$$I = i_1 + i_2 + i_3$$

Second Law: In any closed circuit the algebraic sum of the i r drops is equal to the e. m. fs.

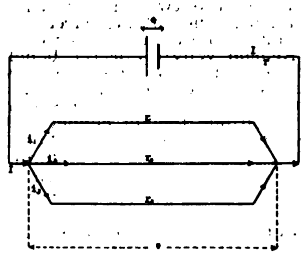


Fig. 1

From Fig. 1

$$i_1r_1 - i_2r_2 = 0$$
$$i_2r_2 - i_3r_3 = 0$$
$$i_1r_1 + Ir = e$$

Shunt Circuit: In any shunt circuit the sum of the reciprocals of the individual resistance equals the reciprocal of the effective or equivalent resistance.

From Fig. 1

$$\frac{1}{R} = \frac{1}{r_1} + \frac{1}{r_2} + \frac{1}{r_3}$$

Series Circuit: In series circuits the resistances are added arithmetically, while the e. m. fs. are added algebraically.

WIRING FORMULA FOR DIRECT CURRENT

Wiring Formula: From Ohm's Law, the proper size of wire that should be used to carry a current any distance with a given loss in volts can be readily determined.

Let l = Distance (one way) in feet.
I = Current in amperes.
CM = Circular mils—cross sectional area of wire.

$$\text{Volts lost} = \frac{l \times 21.5 \times I}{CM}$$

$$\text{Circular mils} = \frac{l \times 21.5 \times I}{\text{volts lost}}$$

In above, the number of feet must be measured one way, not both sides of the circuit; volts lost should be taken as the drop allowed in volts, and circular mils show the size of wire to use.

Example: What size wire should be used on a 250-volt circuit where it is necessary to carry 200 amperes a distance of 350 feet to a center of distribution with a loss of 3 per cent under full load?

3 per cent of 250 = 7.5 volts lost.

$$\frac{350 \times 200 \times 21.5}{7.5} = 200667$$ circular mils, or No. 0000 B. & S. gauge, which is the next size heavier.

In using this or any other formula to determine the size of copper to use, care should be taken to see that the size adopted is not smaller than allowed in the Underwriters' table of safe carrying capacities, which are fixed without considering the loss in line.

The general practice in balanced 3-wire direct current systems with a central neutral wire is to figure the line loss on the same basis as a 2-wire system of the voltage between the two outside wires with the amount of current carried in the outside wires. The central neutral wire should be made the same size as either of the others.

Reason Why: For the benefit of those who care to know the reason why, the above wiring formula is based upon one foot of copper wire, with a cross sectional area of one circular mil, having a resistance very close to 10.75 ohms; or upon one foot of copper wire, with a cross sectional area of 10.75 circular mils, having a resistance very close to 1 ohm. Hence the resistance of any copper wire =

$$\frac{\text{Length in feet} \times 10.75}{\text{circular mils}}$$

Substituting this expression for R in Ohm's Law:

$$E = \frac{I \times \text{length in feet} \times 10.75}{\text{circular mils}}$$

$$\text{and circular mils} = \frac{I \times \text{length in feet} \times 10.75}{E}$$

In the wiring formula, however, the length in feet is considered the "run," or one side of the circuit, hence the resistance is doubled and the term 10.75 must be multiplied by 2.

WIRING FORMULA FOR ALTERNATING CURRENT

Let I = current in line in amperes.
W = energy delivered in watts.
E = voltage between mains.
P.F. = power factor.

Then

$$I = \frac{W}{E \times P.F.} \text{ for single phase circuit.}$$

$$I = 0.50 \times \frac{W}{E \times P.F.} \text{ for two-phase circuit.}$$

$$I = 0.58 \times \frac{W}{E \times P.F.} \text{ for three-phase circuit.}$$

When the power factor cannot be accurately determined it may be assumed as follows: Lighting load with no motors, 0.95; lighting and motors, 0.85; motors only, 0.80.

From the above formula, if W, E and P.F. are the same, it will be seen that:

The current in each wire two-phase equals 0.5 the circuit in each wire single-phase.

The current in each wire three-phase equals 0.58 the current in each wire single phase.

The current in each wire three-phase equals 1.16 the current in each wire two-phase.

In alternating current systems of wiring, single-phase or 4-wire two-phase, that carry non-inductive loads, such as incandescent lamps, the printed formula should be used. When the load is inductive, such as motors or arc lamps, an addition of 25% to the number of circular mils obtained by the wiring formula is recommended if the size of wire required has been figured on the same basis as used for direct current, to compensate for the power factor. Single-

phase 3-wire circuits, if non-inductive, may be figured on the same basis as direct current 3-wire systems.

Three-Phase Wiring: In a 3-wire balanced three-phase system, which is later divided into three single-phase systems, the current in each wire, up to the point where the 3-wire system is divided in 2-wire, is $\sqrt{3}$ (1.732) times the amount it would be if three separate single-phase circuits were used, owing to each wire having to carry current for each phase.

For example, in carrying 600 incandescent lamps of .5 amperes each, 200 on each phase, each phase would carry 100 amperes. The current in each of the three wires, however, would be $100 \times \sqrt{3} = 173.2$ amperes, and this quantity should be used in the wiring formula.

In other respects the three-phase 3-wire system may be figured the same as a 2-wire system, and each of the three wires made the same size.

Three-phase motors generally bear the manufacturer's name plate showing the amperes per phase, which represents the total current in each live wire, so the factor $\sqrt{3}$ should not be used to obtain the size of copper.

In general:

$$\text{h.p.} = \frac{\text{Amps. per phase} \times \text{volts} \times \sqrt{3} \times \text{P.F.}}{746}$$

$$\text{Amps per phase} = \frac{\text{h. p.} \times 746}{\text{volts} \times \sqrt{3} \times \text{P.F.}}$$

The term P.F. is less than unity and varies approximately from 0.65 for 1 h.p. to 0.90 for 50 h.p. motors.

From switchboard voltmeters and ammeters the total load equals:

$$\text{Watts} = \text{amps. per phase} \times \text{volts} \times \sqrt{3} \times \text{P.F.}$$

IMPORTANCE OF HIGH RESISTANCE FOR VOLTMETERS

It is highly important, as reducing the error in measurement, that the internal resistance of a voltmeter be as high as practicable, as is shown in the following example:

Let E in the figure be a dynamo, battery, or other source of electric energy, sending current through the resistance r; and *vm.* be a voltmeter indicating the pressure in volts between the terminals A and B. Before the *vm.* is connected to the terminals A and B there will be a certain difference of potential, which will be less when the voltmeter is connected, owing to the lessening of the total resistance between the two points; if the resistance of the *vm.* be high, this difference will be very small, and the higher it is the less the error. Following are the formulæ and computations for determining the error.

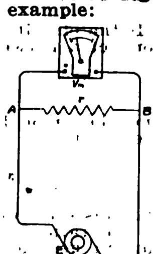


Fig. 2

In Fig. 2 let E be the e.m.f. of the dynamo, r the resistance of the circuit as shown between A and B, and r_1 be the resistance of the leads A and B plus that of the dynamo, and let R be the resistance of the voltmeter; then before the *vm.* is connected the difference between A and B will be

$$e = \frac{r_1}{r + r_1} \times E,$$

and after connecting the voltmeter it will be

$$e_1 = \frac{R \times r}{R \times r + r \times r_1 + r_1 \times R} \times E.$$

The difference between the two results e and e_1 is then

$$e - e_1 = \frac{1}{R} \times \frac{r \times r_1}{r + r_1} \times e_1,$$

and this difference will be smaller the greater the resistance R of the *vm.* is.

Example—

Let

$$E = 10 \text{ volts}$$
$$r = 10 \text{ ohms}$$
$$r_1 = 2 \text{ ohms}$$
$$R = 500 \text{ ohms}$$

then $$e_1 = \frac{500 \times 10}{500 \times 10 + 10 \times 2 + 2 \times 500} \times 10 = 8.3056;$$

and $$e - e_1 = \frac{1}{500} \times \frac{10 \times 2}{10 + 2} \times 10 = .0333.$$

If R be made 1000 ohms, then

$$e_1 = \frac{1000 \times 10}{1000 \times 10 + 10 \times 2 + 2 \times 1000} \times 10 = 8.32,$$

and $$e - e_1 = \frac{1}{1000} \times \frac{10 \times 2}{10 + 2} \times 10 = .0166,$$

or just one half of the error; it may be said that the error is therefore in inverse proportion to the resistance of the *vm.*

If the error of measurement is not to exceed a stated per cent p, then

r and r_1 must be such that $\frac{r \times r_1}{r + r_1}$ is smaller than $\frac{p \times R}{100}$ ohms.

If the circuit is not closed by a resistance r, then with *vm.* connected between A and B

$$e_1 = \frac{R}{R + r_1} \times E,$$

and the error between the true value and that shown on the *vm.* is

$$E - e_1 = \frac{r_1}{R} \times e_1$$

and this error decreases in inverse proportion to the increase of the ratio between R and the internal resistance of the current generator r.

If the error is not to exceed p per cent, then the internal resistance r_1 must be less than $\frac{p \times R}{100}$ ohms.

The e. m. f. of high-resistance cells cannot be correctly measured by the above method, even with voltmeters of

relatively high resistance, but it is better done by one of the methods mentioned below.

COMPARISON OF E. M. F. OF BATTERIES

Wheatstone's Method: To compare e. m. f. of two batteries A and X, with low-reading voltmeters, let E be the e. m. f. of A, and E_1 the e. m. f. of X.

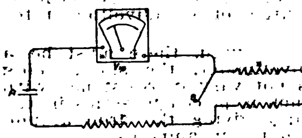


Fig. 3

First connect battery A in series with the voltmeter and a resistance r, switch B being closed, and note the deflection V; then open the switch B, and throw in the resistance r_1, and note the deflection V_1. Now connect battery X in place of A, and close the switch B, and vary the resistance r until the same deflection V of voltmeter is obtained and call the new resistance r_2; next open the switch B, or otherwise add to the resistance r_2 until the deflection V_1 of the voltmeter is produced; call this added resistance r_3, then

$$E : E_1 :: r_1 : r_3.$$

If E be smaller than E_1, the voltmeter resistance R may be taken as r, and it is better to have r_1 about twice as large as the combined resistance of r and the resistance of A.

It is not necessary that the internal resistance of the cells be small as compared with R.

MEASURING CURRENT STRENGTH WITH A VOLTMETER

If the resistance of a part of an electric circuit be known, taking the drop in potential around such resistance will determine the current flowing by Ohm's Law, viz.,

$$I = \frac{E}{R}.$$

In the figure let r be a known resistance between the points A and B of the circuit, and I the strength of current to be determined; then if the voltmeter, connected as shown, gives a deflection of V volts, the current flowing in r will be $I = \dfrac{V}{r}$.

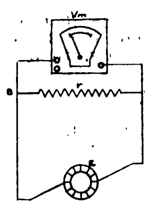


Fig. 4

For the corrections to be applied in certain cases, see the section on *Importance of High Resistance for Voltmeters*.

Always see that the resistance r has enough carrying capacity to avoid a rise of temperature which would change its resistance.

If the reading is exact to $\dfrac{1}{p}$ volt the measurement of current will be exact to $\dfrac{1}{p \times r}$ amperes. If $r = .5$ ohm. and the readings are taken on a low-reading voltmeter, say ranging from 0 to 5 volts, and that can be read to $\frac{1}{100}$ volt, then the possible error will be

$$\frac{1}{300 \times .5} = \frac{1}{150} \text{ ampere.}$$

If r be made equal to 1 ohm, then the volts read also mean amperes.

Measurement of Very Heavy Currents with a Millivoltmeter: For this purpose the method outlined above is most generally used with the substitution of a millivoltmeter for the voltmeter.

Where portable instruments are used, there must be a calibrated shunt for the millivoltmeter, the shunt being made up of a metal that does not vary in resistance with change of temperature, and which is placed in series in the circuit, the millivoltmeter simply giving the drop around this shunt, its scale being graduated in amperes.

For switchboard instruments the method is the same, being varied sometimes by using as a shunt a measured part of a conductor or bus bar in place of a special resistance.

MEASURING RESISTANCE WITH A VOLTMETER

General Methods: In the figure, let X = the unknown resistance that is to be measured. r = a known resistance, E the dynamo or other steady source of e. m. f.

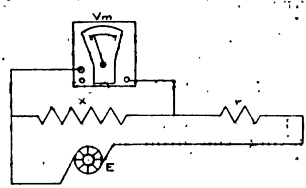


Fig. 5

When connected as shown in the figure, let the voltmeter reading be V; then connect the voltmeter terminals to r in the same manner and let the reading be V_1; then.

$$X : r :: V : V_1$$

and
$$X = \frac{r \times V}{V_1}$$

If, for instance, $r = 2$ ohms and $V = 3$ volts and $V_1 = 4$ volts, then

$$X = \frac{2 \times 3}{4} = 1.5 \text{ ohms.}$$

If readings can be made to $\frac{1}{100}$ volt, the error of resistance measurement will then be

$$100 \times \tfrac{1}{100}\left(\frac{1}{V} + \frac{1}{V_1}\right) \text{ per cent.}$$

and for the above example would be

$$1(\tfrac{1}{3} + \tfrac{1}{4}) = 0.58\%.$$

Should there be a considerable difference between the magnitudes of the two resistances X and r, it might be better to read the drop across one of them from one scale, and to read the drop across the other on a lower scale.

Resistance Measurement with Voltmeter and Ammeter: The most common modification of the above method is to insert an ammeter in place of the resistance r in the last figure, in which case $X = \frac{V}{I}$ where I is the current flowing in amperes as read from the ammeter.

If the readings of the voltmeter be correct to $\frac{1}{100}$ and the

ammeter readings be correct to the same degree, the possible error becomes:

$$100 \times \left(\frac{1}{100\,V} + \frac{1}{100\,I}\right) \text{ per cent.}$$

Measurement of Very Small Resistances with a Millivoltmeter and Ammeter: By using a millivoltmeter in connection with an ammeter, very small resistance, such as those of bars of copper, armature resistance, etc., can be accurately measured.

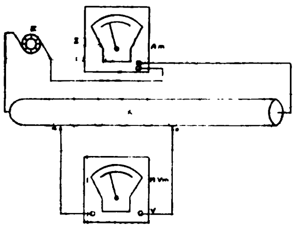


Fig. 6

In order to have a reasonable degree of accuracy in measuring resistance by the "drop" method, as this is called, it is necessary that as heavy currents as may be available be used. Then, if E be the dynamo or other source of steady e. m. f., X be the required resistance of a portion of the bar, V be the drop in potential between the points a and b, and I be the current flowing in the circuit as indicated by the ammeter, then

$$X = \frac{V}{I}$$

The applications of this method are endless, and but a few, to which it is especially adapted, need be mentioned here. They are the resistance of armatures, the drop being taken from opposite commutator bars and not from the brush holders, as then the brush contact resistance is taken in; the resistance of station instruments and all switchboard appliances, such as the resistance of switch contacts; the resistance of bonded joints on electric railway work.

Measurement of High Resistances: With the ordinary voltmeter of high internal resistance, let R be the resistance of the voltmeter, X be the resistance to be measured. Connect them up in series with some source of electro-motive force as in the following figure:

Close the switch b, and read the voltage V with the resistance of the voltmeter alone in circuit; then open the switch, thus cutting in the resistance X, and take another reading of the voltmeter, V_1.

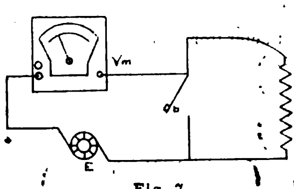


Fig. 7

Then $$X = R\left(\frac{V}{V_1} - 1\right)$$

If the readings of the voltmeter be correct to 1/10 of a volt the error of the above result will be

$$\frac{10}{V_1}\left(\frac{V + V_1}{V - V_1}\right) \text{ per cent.}$$

MEASURING THE INSULATION OF LIGHTING AND POWER CIRCUITS WITH A VOLTMETER

For rough measurements, where the exact insulation resistance is not required, but it is wished to determine if such resistance exceeds some stated figure or rate, then the method above given will do, when applied as follows:

Let X = Insulation resistance to ground as in figure.
$X_{,}$ = Insulation resistance to ground of opposite lead.
R = Resistance of voltmeter.
V = Potential of dynamo E.
$V_{,}$ = Reading of voltmeter, as connected in figure.
$V_{,,}$ = Reading of voltmeter, when connected to opposite lead.

Then $X = R\left(\frac{V}{V_{,}} - 1\right)$

and $X_{,} = R\left(\frac{V}{V_{,,}} - 1\right)$.

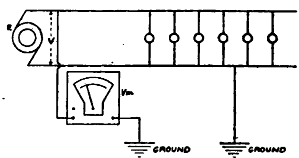


Fig. 8

The above formula can be modified to give results more nearly correct by taking into account the fact that the path through the resistance R of the voltmeter is in parallel with the leak to ground on the side to which it is connected as shown in the following figure:

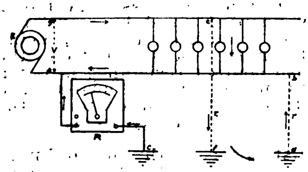


Fig. 9

In this case the voltage V of the circuit will not only send current through the lamps, but through the leaks e f to ground, and through the ground to d and c, thence through d to b, and c to a, these two last paths being in parallel, therefore having less resistance than if one alone was used; thus if r be the resistance of the ground leak b d, and r_{1} be the resistance of the leak e f, and R be the resistance of the voltmeter, then the total resistance by way of the ground, between the conductors, would be

$$\frac{R \times r}{R + r} + r_1$$

and if V = voltage of the circuit,
v = reading of voltmeter from a to c,
$v_{,}$ = reading of voltmeter from g to c,

Then $$r = R\left(\frac{V - (v + v_{,})}{v_{,}}\right),$$

and $$r_1 = R\left(\frac{V - (v + v_{,})}{v}\right),$$

The sum of the resistance $r + r_1$ will be $R\left(\frac{(v + v_{,})\,(V - (v + v_{,}))}{v + v_{,}}\right)$.

MEASURING THE INSULATION OF DYNAMOS

The same formula as that used for measuring high resistances (see Fig. 7) applies equally well to determining the insulation of dynamo conductors from the iron body of the machine.

Connect as in Fig. 10 all symbols having the same meaning as before.

Let r = insulation resistance of dynamo, then

$$r = R\left(\frac{V}{V_1} - 1\right)$$

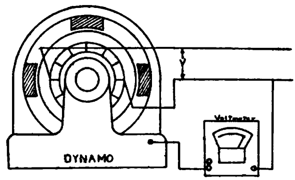


Fig. 10

MEASURING THE INSULATION RESISTANCE OF MOTORS

Where motors are connected to isolated plant circuits with known high insulation, the formula used for insulation of dynamos applies; but where the motors are connected to public circuits of questionable insulation it is necessary to first determine the circuit insulation, which can be done by using the connections shown in Fig. 8. Fig. 11 shows the connections to motor for determining its insulation by current from an operating circuit.

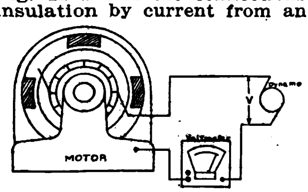


Fig. 11

Here, as before, the insulation r of the total connected devices =

$$R\left(\frac{V}{V_1} - 1\right).$$

If r = total resistance of circuit and motor in multiple to ground, and r_1 is the insulation of the circuit from ground, then X, the insulation of the motor, will be

$$X = \frac{r_1 \times r}{r_1 - r}.$$

MEASUREMENT OF THE INTERNAL RESISTANCE OF A BATTERY

In the following figure (No. 12), let E be the cell or battery whose resistance is to be measured, K be a switch, and r_1 a suitable resistance.

Let V = the reading of voltmeter with the key, K, open (this is the e. m. f. of the battery), and

V_1 = the reading of voltmeter with key, K, closed (this is the drop across the resistance r). Then the battery resistance

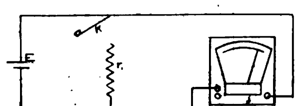


Fig. 12

$$r_1 = r \times \frac{V - V_1}{V} \text{ ohms.}$$

WROUGHT IRON WELDED STEAM, GAS AND WATER PIPE—Table of Standard Dimensions

Diameter			Thickness	Circumference		Transverse Areas			Length of Pipe per Square Foot of		Length of Pipe Containing one Cu. Ft.	Nominal Weight per Foot	Number of Threads per Inch of Screw
Nominal Internal	Actual External	Actual Internal		External	Internal	External	Internal	Metal	External Surface	Internal Surface			
Inches	Inches	Inches	Inches	Inches	Inches	Sq Ins.	Sq. Ins.	Sq. Ins.	Feet	Feet	Feet	Pounds	
1/8	.405	.27	.068	1.272	.848	129	0573	.0717	9.44	14.15	2513.	.241	27
1/4	.54	.364	.088	1.696	1.144	229	.1041	.1249	7.075	10.49	1383.3	.42	18
3/8	.675	494	.091	2.121	1.552	.358	.1917	.1663	5.657	7.73	751.2	.559	18
1/2	.84	.623	.109	2.639	1.957	.554	.3048	.2492	4.547	6.13	472.4	.837	14
3/4	1.05	.824	.113	3.299	2.589	.866	.5333	.3327	3.637	4.635	270.	1.115	14
1	1.315	1.048	.134	4.131	3.292	1.358	.8626	.4954	2.904	3.645	166.9	1.668	11½
1¼	1.66	1.38	.14	5.215	4.335	2.164	1.496	.668	2.301	2.768	96.25	2.244	11½
1½	1.9	1.611	145	5.969	5.061	2.835	2.038	.797	2.01	2.371	70.66	2.678	11½
2	2.375	2.067	.154	7.461	6.494	4.43	3.356	1.074	1.608	1.848	42.91	3.609	11½
2½	2.875	2.468	.204	9.032	7.753	6.492	4.784	1.708	1.328	1.547	30.1	5.739	8
3	3.5	3.067	.217	10.996	9.636	9.621	7.388	2.243	1.091	1.245	19.5	7.536	8
3½	4.	3.548	.226	12.566	11.146	12.566	9.887	2.679	.955	1.077	14.57	9.001	8
4	4.5	4.026	.237	14.137	12.648	15.904	12.73	3.174	.849	.949	11.31	10.665	8
4½	5.	4.508	.246	15.708	14.162	19.635	15.961	3.674	.764	.848	9.02	12.34	8
5	5.563	5.045	.259	17.477	15.849	24.306	19.99	4.316	.687	.757	7.2	14.502	8
6	6.625	6.065	.28	20.813	19.054	34.472	28.888	5.584	.577	.63	4.98	18.762	8
7	7.625	7.023	.301	23.955	22.063	45.664	38.738	6.926	.501	.544	3.72	23.271	8
8	8.625	7.982	.322	27.096	25.076	58.426	50.04	8.386	.443	.478	2.88	28.177	8
9	9.625	8.937	.344	30.238	28.076	72.76	62.73	10.03	.397	.427	2.29	33.701	8
10	10.75	10.019	.366	33.772	31.477	90.763	78.839	11.924	.355	.382	1.82	40.065	8
11	12.	11.25	.375	37.699	35.343	113.098	99.402	13.696	.318	.339	1.456	45.95	8
12	12.75	12.	.375	40.055	37.7	127.677	113.098	14.579	.299	.319	1.27	48.985	8
13	14.	13.25	.375	43.982	41.626	153.938	137.887	16.051	.273	.288	1.04	53.921	8
14	15.	14.25	.375	47.124	44.768	176.715	159.485	17.23	.255	.268	.903	57.893	8
15	16.	15.25	.375	50.265	47.909	201.062	182.655	18.407	.239	.250	.788	61.77	8
....	18.	17.25	.375	56.549	54.192	254.47	233.706	20.764	.212	.221	.616	69.66	....
....	20.	19.25	.375	62.832	60.476	314.16	291.04	23.12	.191	.198	.495	77.57	....
....	22.	21.25	.375	69.115	66.759	380.134	354.657	25.477	.174	.179	.406	85.47	....
....	24.	23.25	.375	75.398	73.042	452.39	424.558	27.832	.159	.164	.389	93.37	....

TABLE OF EQUATION OF PIPES
(Standard Steam and Gas Pipes.)

Dia.	½	¾	1	1½	2	2½	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	Dia.
½		2.27	4.88	15.8	31.7	52.9	96.9	205	377	620	918	1292	1767	2488	3014	3786	4904	5927	7321	8535	9717	½
¾	2.60		2.05	6.97	14.0	23.3	42.5	90.4	166	273	405	569	779	1096	1328	1668	2161	2615	3226	3761	4282	¾
1	7.55	2.90		3.45	6.82	11.4	20.9	44.1	81.1	133	198	278	380	536	649	815	1070	1263	1576	1837	2092	1
1½	24.2	9.30	3.20		1.26	3.34	6.13	13.0	23.8	39.2	58.1	81.7	112	157	190	239	310	375	463	539	614	1½
2	54.8	21.0	7.25	2.26		1.67	3.06	6.47	11.9	19.6	29.0	40.8	55.8	78.5	95.1	119	155	187	231	269	307	2
2½	102	39.4	13.6	4.23	1.87		1.83	3.87	7.12	11.7	17.4	24.4	33.4	47.0	56.9	71.5	92.6	112	138	161	184	2½
3	170	65.4	22.6	7.03	3.11	1.66		2.12	3.89	6.39	9.48	13.3	20.9	23.7	31.2	39.1	50.6	61.1	75.5	88.0	100	3
4	376	144	49.8	15.5	6.87	3.67	2.21		1.84	3.02	4.48	6.30	8.61	12.1	14.7	18.5	23.9	28.9	35.7	41.6	47.4	4
5	686	263	90.9	28.3	12.5	6.70	4.03	1.83		1.65	2.44	3.43	4.69	6.60	8.00	10.0	13.0	15.7	19.4	22.6	25.8	5
6	1116	429	148	46.0	20.4	10.9	6.56	2.97	1.63		1.48	2.09	2.85	4.02	4.86	6.11	7.91	9.56	11.8	13.8	15.6	6
7	1707	656	226	70.5	31.2	16.6	10.0	4.54	2.49	1.51		1.41	1.93	2.71	3.28	4.12	5.34	6.45	7.97	9.31	10.6	7
8	2435	936	322	101	44.5	23.8	14.3	6.48	3.54	2.18	1.43		1.35	1.93	2.33	2.92	3.79	4.57	5.67	6.60	7.52	8
9	3335	1281	440	137	60.8	32.5	19.5	8.85	4.85	2.98	1.95	1.37		1.41	1.71	2.14	2.77	3.35	4.14	4.83	5.50	9
10	4393	1688	582	181	80.4	42.9	25.8	11.7	6.40	3.93	2.57	1.80	1.32		1.21	1.52	1.97	2.38	2.94	3.43	3.91	10
11	5642	2168	747	233	103	55.1	33.1	15.0	8.22	5.05	3.31	2.32	1.70	1.28		1.26	1.63	1.88	2.43	2.83	3.22	11
12	7087	2723	938	293	129	69.2	41.6	18.8	10.3	6.34	4.15	2.91	2.13	1.61	1.26		1.30	1.57	1.93	2.26	2.58	12
13	8657	3326	1146	358	158	84.5	50.7	23.0	12.6	7.75	5.07	3.56	2.60	1.98	1.53	1.22		1.21	1.49	1.74	1.98	13
14	10600	4070	1403	438	193	103	62.2	28.2	15.4	9.48	6.21	4.35	3.18	2.41	1.88	1.50	1.22		1.24	1.44	1.64	14
15	12824	4927	1698	530	234	125	75.3	34.1	18.7	11.5	7.52	5.27	3.85	2.92	2.27	1.81	1.48	1.21		1.17	1.35	15
16	14978	5758	1984	619	274	146	88.0	39.9	21.8	13.4	8.78	6.15	4.51	3.41	2.66	2.12	1.73	1.42	1.18		1.14	16
17	17537	6738	2322	724	320	171	103	46.6	25.6	15.7	10.3	7.20	5.27	3.99	3.11	2.47	2.03	1.66	1.37	1.17		
18	20327	7810	2691	840	371	198	119	54.1	29.6	18.2	11.9	8.35	6.11	4.63	3.60	2.87	2.35	1.92	1.59	1.36	1.16	
20	26676	10249	3532	1102	487	260	157	70.9	38.9	23.9	15.6	10.9	8.02	6.07	4.73	3.76	3.08	2.52	2.08	1.78	1.52	
24	42624	16376	5644	1761	778	416	250	113	62.1	38.2	25.0	17.5	12.8	9.70	7.55	6.01	4.92	4.02	3.32	2.84	2.43	
30	75453	28990	9990	3117	1378	736	443	201	110	67.6	44.2	31.0	22.7	17.2	13.4	10.7	8.72	7.14	5.88	5.03	4.30	
36	120100	46143	15902	4961	2193	1172	705	319	175	108	70.4	49.3	36.1	27.3	21.3	16.9	13.9	11.3	9.37	8.01	6.85	
42	177724	68282	23531	7341	3245	1734	1044	473	259	159	104	73.0	53.4	40.5	31.5	25.1	20.5	16.8	13.9	11.9	10.1	
48	249351	95818	33020	10301	4554	2434	1465	663	363	223	146	102	75.0	56.8	44.2	35.2	28.8	23.5	19.4	16.6	14.2	

Actual Internal Diameters

CONDUIT SIZES FOR DIFFERENT SIZE WIRES

No. B. & S.	Circular Mils	Amperes Rubber	Size of Pipe 1 Wire	2 Wire	3 Wire
18	1,624	3	½	½	½
16	2,583	6	½	½	½
14	4,107	12	½	½	¾
12	6,530	17	½	¾	¾
10	10,380	24	½	¾	1
8	16,510	33	½	1	1
6	26,250	46	¾	1	1¼
5	33,100	54	¾	1¼	1¼
4	41,740	65	¾	1¼	1½
3	52,630	76	¾	1¼	1½
2	66,370	90	¾	1½	2
1	83,690	107	1	1½	2
0	105,500	127	1	2	2
00	133,100	150	1	2	2
000	167,800	177	1¼	2	2½
0000	211,600	210	1¼	2	2½
....	200,000	200	1¼	2	2½
....	250,000	235	1½	2½	2½
....	300,000	270	1½	2½	3
....	350,000	300	1½	2½	3
....	400,000	330	1½	3	3
....	450,000	380	2	3	3½
....	500,000	390	2	3	3½
....	550,000	420	2	3½	4
....	600,000	450	2	3½	4
....	650,000	475	2	3½	4
....	700,000	500	2	3½	4
....	750,000	525	2	3½	4
....	800,000	550	2	3½	4
....	850,000	575	2½	4	4
....	900,000	600	2½	4	4½
....	950,000	625	2½	4	4½
....	1,000,000	650	2½	4	4½
....	1,100,000	690	2½	4	5
....	1,200,000	730	2½	4	5
....	1,300,000	770	2½	4½	5
....	1,400,000	810	3	4½	6
....	1,500,000	850	3	5	6
....	1,600,000	890	3	5	6
....	1,700,000	930	3	5	6
....	1,800,000	970	3	6	7
....	1,900,000	1,010	3	6	7
....	2,000,000	1,050	3	6	7

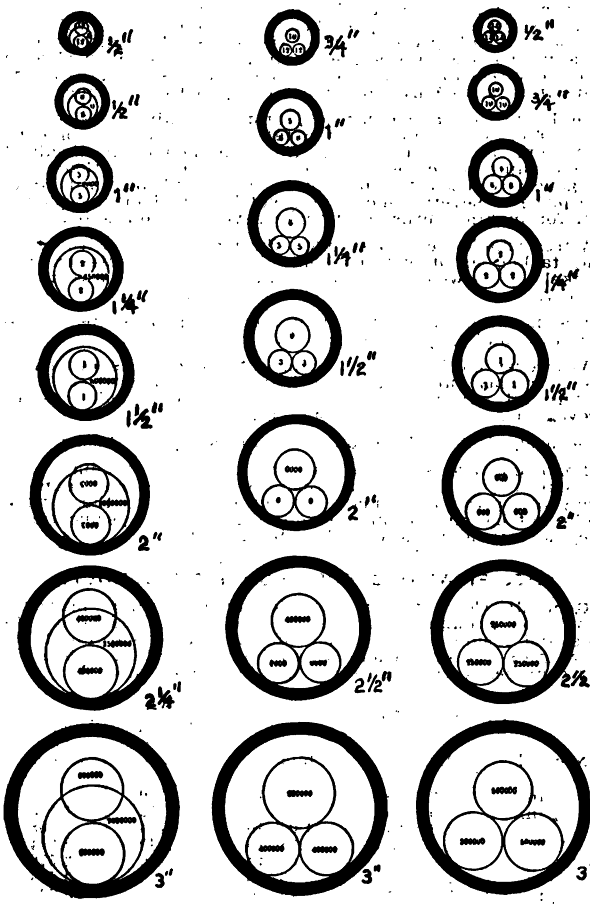


Fig. 13

The table of Equation of Pipes, page 259, gives the number of pipes of one size required to equal in delivery larger pipes of equal length and conditions. That portion of the table above the diagonal line pertains to "standard" steam and gas pipes. That part below this line refers to pipes of the "actual" given internal diameters. The intersection of any two sizes gives the number of the smaller size of pipe required to equal one of the larger size in delivery. Thus it requires 8 five-inch pipes to equal 1 eleven-inch pipe.

In laying out a conduit job, first ascertain the size and number of wire required, then take the proper size of conduit from table on page 260. One-half inch is the smallest size conduit permitted by the National Electric Code and is generally used for branches. One pull box will take the place of several elbows and will be found most economical for making turns in running several conduits together.

Wires should never be pulled through conduit with block and tackle, as it will not only injure the insulation but is likely to so wedge the wires that they cannot be removed readily.

Use no other lubricants than Ivory soap or soapstone to facilitate pulling wires in conduit.

Wherever conduit is cut ream out the end, as otherwise the burr may cut through the insulation on the wires.

Plug all exposed ends of conduit in new buildings to prevent plaster and dirt from falling into it.

Securely fasten all conduit by pipe straps or hooks.

Following are specifications for iron pipe conduit used by one of the largest railroad systems in this country. They are given as a matter of information to those who, while not having anything to do with writing specifications, are, nevertheless, more or less interested.

SPECIFICATIONS FOR IRON PIPE CONDUIT

General: Conduit for electric train-lighting purposes should be wrought iron or steel pipe, galvanized both outside and inside, and should conform to the following table of weights and dimensions, a maximum variation of five (5) per cent below the respective weights being allowed.

Diameter of Conduit			Thickness of Metal Inches	Weight per Foot Pounds
Nominal	External	Internal		
½ in.	.840 in.	.620 in.	.110	.85
¾ in.	1.05 in.	.824 in.	.113	1.115
1 in.	1.315 in.	1.047 in.	.134	1.668
1¼ in.	1.660 in.	1.380 in.	.140	2.244
1½ in.	1.900 in.	1.610 in.	.145	2.670
2 in.	2.375 in.	2.067 in.	.154	3.609
2½ in.	2.875 in.	2.467 in.	.204	5.739
3 in.	3.500 in.	3.066 in.	.217	7.536

Lengths: The conduit should be furnished in lengths of ten (10) feet, each end being threaded with a standard pipe thread, and with each length should be furnished one coupling; provided, however, that, if desired, the conduit may be ordered cut to specified lengths.

Galvanizing: The interior of the conduit must be free from burrs and fins and the ends of the conduit should be cut square and reamed smooth. Pipe and couplings should be galvanized separately.

All bends of the radius given in the following table or smaller should be galvanized after bending.

Size of Pipe	Radius of Bend
½ in.	4.25 in.
¾ in.	5.50 in.
1 in.	5.75 in.
1¼ in.	7.25 in.
1½ in.	8.50 in.

All blistered or defective pieces of conduit should be rejected.

Tests: Two samples, not less than one foot in length, of each size of conduit should be selected at random from each one thousand (1000) feet or fraction thereof of conduit ordered, and tested as follows:

The sample should be immersed in a standard solution of copper sulphate for one (1) minute, then removed and immediately washed thoroughly in water and wiped dry. This process to be repeated twice. If after the second (2) immersion, there should be a copper-colored deposit on the sample or the zinc should have been removed the sample to be considered as failing to pass the test.

Standard Solution Cu SO_4: The standard solution of copper sulphate (Cu SO_4) consists of a solution of commercial copper sulphate crystals in water. This solution should have a specific gravity of 1.185 at 70° Fahr. While the sample is being tested the temperature of the standard solution should at no time be less than 60° or more than 80° Fahr.

SECTION X

GENERAL DATA

INCLUDING GEARS, BELTING, PULLEYS, SHAFTING, ROPE DRIVE, BEARINGS AND FRICTION

GEARING

The circular pitch of a gear wheel is the distance in inches measured on the pitch circle from the center of one tooth to the center of the next tooth.

If the distance of the teeth of a gear thus measured were 2½ inches, we would say that the circular pitch was 2½ inches.

Let P = Circular pitch.
D = Diameter of pitch circle, in inches.
C = Circumference of pitch circle, in inches.
N = Number of teeth.
$\pi = 3.1416$.

$$P = \frac{C}{N} \text{ or } \frac{\pi D}{N} \qquad N = \frac{C}{P} \text{ or } \frac{\pi D}{P}$$

$$C = PN \text{ or } \pi D \qquad D = \frac{PN}{\pi} \text{ or } \frac{C}{\pi}$$

Addendum = .3 P. Root = .4 P.

Thickness of teeth for cut gear = .5 P; for cast gear .48 P.

The diametral pitch of a gear wheel is the number of teeth in the wheel divided by the diameter of the pitch circle in inches, or, it is the number of teeth on the circumference of the gear wheel for one inch diameter of pitch circle.

A gear with a pitch diameter of 5 inches and having 40 teeth is 8 pitch; one with the same pitch diameter and having 70 teeth is 14 pitch.

In the gear of 8 pitch there are 8 teeth on the circumference for each inch of the diameter of the pitch circle; and in one of 14 pitch there are 14 teeth on the circumference for each inch of the diameter of the pitch circle.

Let P = Diametral pitch.
D = Diameter of pitch circle, in inches.
N = Number of teeth.
d = Outside diameter.
l = Length of tooth.
t = Thickness of tooth.

$$P = \frac{N}{D} \qquad D = \frac{N}{P} \qquad N = PD. \qquad d = \frac{N+2}{P} \qquad l = \frac{2.157}{P}, \qquad t = \frac{1.57}{P}.$$

The circular pitch corresponding to any diametral pitch may be found by dividing 3.1416 by the diametral pitch; and the diametral pitch corresponding to any circular pitch may be found by dividing 3.1416 by the circular pitch.

(*a*) If the diametral pitch of a gear is 6, the corresponding circular pitch is $\frac{3.1416}{6} = .5236$ in.

(*b*) If the circular pitch is 1.5708 inches, the corresponding diametral pitch is $\frac{3.1416}{1.5708} = 2$.

GEAR TABLE—DIAMETRAL PITCH

Diametral Pitch is the Number of Teeth to Each Inch of the Pitch Diameter

To Get	Having	Rule
Diametral pitch	Circular pitch	Divide 3.1416 by the circular pitch.
Diametral pitch	Pitch diameter and number of teeth	Divide number of teeth by pitch diameter.
Diametral pitch	Outside diameter and number of teeth	Divide number of teeth plus 2 by outside diameter.
Pitch diameter	Number of teeth and diametral pitch	Divide number of teeth by the diametral pitch.
Pitch diameter	Number of teeth and outside diameter	Divide the product of outside diameter and number of teeth by number of teeth plus 2.
Pitch diameter	Outside diameter and diametral pitch	Subtract from outside diameter the quotient of 2 divided by the diametral pitch.
Pitch diameter	Addendum and number of teeth	Multiply addendum by the number of teeth.
Outside diameter	Number of teeth and diametral pitch	Divide number of teeth plus 2 by the diametral pitch.
Outside diameter	Pitch diameter and diametral pitch	Add to the pitch diameter the quotient of 2 divided by the diametral pitch.
Outside diameter	Pitch diameter and number of teeth	Divide product of number of teeth plus 2 and pitch diameter by the number of teeth.
Outside diameter	Number of teeth and addendum	Mutiply the number of teeth plus 2 by addendum.
Number of teeth	Pitch diameter and diametral pitch	Multiply pitch diameter by the diametral pitch.
Number of teeth	Outside diameter and diametral pitch	Multiply outside diameter by the diametral pitch and subtract 2.
Thickness of teeth	Diametral pitch	Divide 1.5708 by the diametral pitch.
Addendum	Diametral pitch	Divide 1 by the diametral pitch, or $s = \frac{D'}{N}$
Root	Diametral pitch	Divide 1.157 by the diametral pitch.
Working depth	Diametral pitch	Divide 2 by the diametral pitch.
Whole depth	Diametral pitch	Divide 2.157 by the diametral pitch.
Clearance	Diametral pitch	Divide .157 by the diametral pitch.
Clearance	Thickness of tooth	Divide thickness of tooth at pitch line by 10.

Diametral Pitches With Their Corresponding Circular Pitches

Diametral Pitch, or Teeth per inch in Diameter	Corresponding Circular Pitch	Diametral Pitch, or Teeth per inch in Diameter	Corresponding Circular Pitch
1	3.1416	8	.3927
2	1.5708	9	.3491
3	1.0472	10	.3142
4	.7854	12	.2618
5	.6283	14	.2244
6	.5236	16	.1963
7	.4488	20	.1571

BELTING

D = Diameter of larger pulley in inches.
d = Diameter of smaller pulley in inches.
N = Revolutions per minute of larger pulley.
n = Revolutions per minute of smaller pulley.
W = Width of double belt in inches.
w = Width of single belt in inches.
H = Horsepower that can be transmitted by the belt.

Then, $H = \frac{D\,N\,w}{2750}$ for single belts.

$H = \frac{D\,N\,W}{1925}$ for double belts.

$$w = \frac{2750\ H}{D\,N} = \frac{2750\ H}{d\,n};\quad W = \frac{1925\ H}{D\,N} = \frac{1925\ H}{d\,n}.$$

$D = \frac{2750\ H}{w\,N}$ for single belt.

$D = \frac{1625\ H}{W\,N}$ for double belt.

$N = \frac{2750\ H}{w\,D}$ for single belt.

$N = \frac{1925\ H}{W\,D}$ for double belt.

The above rules are for open belts and pulleys having the same diameter, the arc of contact being, in this case, half the circumference, or 180°. For open belts and pulleys of different diameters, the arc of contact is less than 180° on the smaller pulley, and a different constant, to be taken from the following table, must be substituted in the formulæ. To find the arc of contact, let l be the distance in inches between the centers of the pulleys. Then $\frac{D - d}{2\,l}$ = cosine of half the angle. Find this half angle from a table of natural cosines, and multiply by 2. The result is the arc of contact in degrees. Find the number in the first column of the table which is nearest to this result, and use the constant corresponding to that number. If a table of natural cosines is not at hand, measure the length of the arc

of contact on the smaller pulley and divide it by the circumference of the pulley. Find the fraction in the second column which corresponds nearest to this result, and opposite this, its corresponding constant.

Degrees	Fraction of Circumference	Single Belt Constant	Double Belt Constant
90	$\frac{1}{4} = .25$	6080	4250
$112\frac{1}{2}$	$\frac{5}{16} = .3125$	4730	3310
120	$\frac{1}{3} = .3333$	4400	3080
135	$\frac{3}{8} = .375$	3850	2700
150	$\frac{5}{12} = .4167$	3410	2390
$157\frac{1}{2}$	$\frac{7}{16} = .4375$	3220	2250
180 to 270	$\frac{1}{2}$ to $\frac{3}{4} = .5$ to $.75$	2750	1925

For example, what must be the width of a single belt to transmit 12 horsepower, when the diameter of the larger pulley is 42 inches, of the smaller pulley 20 inches, distance between their centers 14 feet = 168 inches, and r. p. m. of smaller pulley 150?

$$\frac{42 - 20}{2 \times 168} = .06548 = \text{cosine of half the arc of contact, which}$$

thus = 86° 15′, nearly; 86° 15′ × 2 = 172½° = the arc of contact; the nearest number in the table is 180° and the corresponding constant is 2,750; hence $w = \frac{2{,}750 \times 12}{20 \times 150} = 11$ inches.

Oak-tanned leather makes the best belts. When belts are run with the hair side over the pulley, they have greater adhesion.

The ordinary thickness of leather belts is 3/16 inch, and weight about 60 pounds per cubic foot.

Ordinarily, four-ply cotton belting is considered equivalent to single leather belting.

RULES FOR CALCULATING THE SPEED OF GEARS OR PULLEYS

In calculating for gears, multiply or divide by the diameter or the number of teeth, as may be required. In calculating for pulleys, multiply or divide by their diameter in inches.

The driving wheel is called the driver, and the driven wheel the driven.

Problem 1

The revolutions of driver and driven, and the diameter of driven being given, required the diameter of driver.

Rule: Multiply the diameter of driven by its number of revolutions, and divide by the number of revolutions of the driver.

Problem 2

The diameter and revolutions of the driver being given, required the diameter of the driven to make a given number of revolutions in the same time.

Rule: Multiply the diameter of the driver by its number of revolutions, and divide the product by the required number of revolutions.

Problem 3

The diameter or number of teeth, and number of revolutions of the driver, with the diameter or number of teeth of the driven being given, required the revolutions of the driven.

Rule: Multiply the diameter or number of teeth of the driver by its number of revolutions, and divide by the diameter or number of teeth of the driven.

Problem 4

The diameter of driver and driven, and the number of revolutions of driven being given, required the number of revolutions of the driver.

Rule: Multiply the diameter of driven by its number of revolutions, and divide by the diameter of the driver.

PULLEYS

To Find Size of Pulley

D = Diameter of driver, or number of teeth in gear.
d = Diameter of driven, or number of teeth in pinion.
Rev = Revolutions per minute of driver.
rev = Revolutions per minute of driven.

$$D = \frac{d \times rev}{Rev}. \qquad Rev = \frac{d \times rev}{D}.$$

$$d = \frac{D \times Rev}{rev}. \qquad rev = \frac{D \times Rev}{d}.$$

BELTING

Horsepower of a Belt One Inch Wide, Arc of Contact 180

Comparison of Different Formulae

Velocity in Feet per Second	Velocity in Feet per Minute	Square Ft. of Belt per Minute	Form. 1 h. p.= $\frac{wv}{550}$.	Form. 2 h. p.= $\frac{wv}{1100}$.	Form. 3 h. p.= $\frac{wv}{1000}$.	Form. 4 h. p.= $\frac{wv}{733}$.	Form. 5 Double Belt h. p.= $\frac{wv}{513}$.	Nagle's Form. $\frac{7}{32}$" Single Belt Lac'd	Nagle's Form. $\frac{7}{32}$" Single Belt Riveted
10	600	50	1.09	.55	.60	.82	1.17	.73	1.14
20	1200	100	2.18	1.09	1.20	1.64	2.34	1.54	2.24
30	1800	150	3.27	1.64	1.80	2.46	3.51	2.25	3.31
40	2400	200	4.36	2.18	2.40	3.27	4.68	2.90	4.33
50	3000	250	5.45	2.73	3.00	4.09	5.85	3.48	5.26
60	3600	300	6.55	3.27	3.60	4.91	7.02	3.95	6.09
70	4200	350	7.63	3.82	4.20	5.73	8.19	4.29	6.78
80	4800	400	8.73	4.36	4.80	6.55	9.36	4.50	7.36
90	5400	450	9.82	4.91	5.40	7.37	10.53	4.55	7.74
100	6000	500	10.91	5.45	6.00	8.18	11.70	4.41	7.96
110	6600	550	....	....	....	....	....	4.05	7.97
120	7200	600	....	....	....	....	....	3.49	7.75

Width of Belt for a Given Horsepower

The width of belt required for any given horsepower may be obtained by transposing the formulæ for horsepower so as to give the value of w. Thus:

From formula (1), $w = \frac{550 \text{ h.p.}}{v} = \frac{9.17 \text{ h.p.}}{V} = \frac{2101 \text{ h.p.}}{d \times rpm} = \frac{275 \text{ h.p.}}{L \times rpm}$

From formula (2), $w = \dfrac{1100\text{ h.p.}}{v} = \dfrac{18.33\text{ h.p.}}{V} = \dfrac{4202\text{ h.p.}}{d \times rpm} = \dfrac{530\text{ h.p.}}{L \times rpm}$

From formula (3), $w = \dfrac{1000\text{ h.p.}}{v} = \dfrac{16.67\text{ h.p.}}{V} = \dfrac{3820\text{ h.p.}}{d \times rpm} = \dfrac{500\text{ h.p.}}{L \times rpm}$

From formula (4), $w = \dfrac{733\text{ h.p.}}{v} = \dfrac{12.22\text{ h.p.}}{V} = \dfrac{2800\text{ h.p.}}{d \times rpm} = \dfrac{360\text{ h.p.}}{L \times rpm}$

From formula (5),* $w = \dfrac{513\text{ h.p.}}{v} = \dfrac{8.56\text{ h.p.}}{V} = \dfrac{1960\text{ h.p.}}{d \times rpm} = \dfrac{257\text{ h.p.}}{L \times rpm}$

* For double belts.

Length of Belt

Approximate rule; two pulleys $\left[\left(\dfrac{Dia_1 + Dia_2}{2}\right) \times 3.1416\right] + [2 \times$ distance between centers] = length of belt.

Length of Belt in Roll

Outside diameter roll in inches + diameter hole × number turns × .1309 = length of belt in inches for double belt.

Weight of Belt (approximate)

$\dfrac{\text{Length in feet} \times \text{width in inches}}{13}$ = weight of single belt. Divide by 8 for double belts.

Horsepower Transmitted by Light, Double Endless Leather Belting

(Buckley)

Speed in feet per min. / Width, Inches	4	6	8	10	12	14	16	18	20	22	24
2000	14	22	29	36	43	50	58	65	72	80	87
2400	17	26	35	44	52	60	70	78	88	96	105
2800	20	30	40	51	61	71	81	91	102	112	122
3000	22	33	44	54	65	76	87	98	108	120	131
3500	25	38	50	63	76	89	101	114	127	140	153
4000	29	43	58	73	87	101	116	131	145	160	174
4500	32	49	65	82	98	114	131	147	163	180	196
5000	36	55	73	91	109	127	145	163	182	200	218
5500	40	60	80	100	120	140	160	180	200	220	240
6000	44	65	87	109	130	153	175	200	218	240	260

(Speed × width ÷ 550 = horsepower, light, double.)
(Horsepower × 550 ÷ speed = width, light, double.)

Horsepower Transmitted by Heavy, Double Endless Leather Belting

Width, Inches / Speed in feet per min.	4	6	8	10	12	14	16	18	20	22	24
2000	18	27	36	43	51	60	70	80	86	96	104
2400	21	31	42	53	62	72	83	94	105	115	120
2800	24	36	48	61	73	85	96	109	122	135	146
3000	27	40	53	65	78	90	104	118	129	144	157
3500	30	45	60	75	91	106	121	137	152	168	184
4000	35	52	70	88	104	121	139	157	174	192	209
4500	38	59	78	98	118	137	157	176	196	216	235
5000	43	66	87	110	130	152	174	196	218	240	262
5500	48	72	96	120	144	168	192	216	240	264	288
6000	52	78	104	122	153	183	210	240	262	288	312

(Speed × width ÷ 460 = horsepower, heavy, double.)
(Horsepower × 460 ÷ speed = width, heavy, double.)

SHAFTING, PULLEYS, BELTING, ROPE-DRIVING

Shafting

Thurston gives the following formulæ for calculating power and size of shafting:

$h.p.$ = horsepower transmitted
d = diameter of shaft in inches.
r = revolutions per minute.

For head shafts well supported against springing:

For iron, $h.\ p. = \frac{d^3 r}{125}$; $d = \sqrt[3]{\frac{125\ h.\ p.}{r}}$

For cold-r'll'd iron, $h.\ p. = \frac{d^3 r}{75}$; $d = \sqrt[3]{\frac{75\ h.\ p.}{r}}$

For line shafting hangers 8 feet apart.

For iron, $h.\ p. = \frac{d^3 r}{90}$; $d = \sqrt[3]{\frac{90\ h.\ p.}{r}}$

For cold-r'll'd iron, $h.\ p. = \frac{d^3 r}{55}$; $d = \sqrt[3]{\frac{55\ h.\ p.}{r}}$

For transmission simply, no pulleys.

For iron, $h.\ p. = \frac{d^3 r}{62.5}$; $d = \sqrt[3]{\frac{62.5\ h.\ p.}{r}}$

For cold-r'll'd iron, $h.\ p. = \frac{d^3 r}{35}$; $d = \sqrt[3]{\frac{35\ h.\ p.}{r}}$

Jones & Laughlin use the same formulæ, with the following exceptions:

For line shafts, cold-rolled iron, . $h.\ p. = \frac{d^3 r}{50}$; $d = \sqrt[3]{\frac{50\ h.\ p.}{r}}$

For transmission and for short-counters:

Turned iron, ... $h.p. = \dfrac{d^3 r}{50}$; $d = \sqrt[3]{\dfrac{50\ h.p.}{r}}$

Cold-rolled iron, ... $h.p. = \dfrac{d^3 r}{30}$; $d = \sqrt[3]{\dfrac{30\ h.p.}{r}}$

Pulleys should be placed as near to bearings as practicable, but care should be taken that oil does not drip from the box into the pulley.

The diameter of a shaft safe to carry the main pulley at the center of a bay may be found by multiplying the fourth power of the diameter obtained by the formulæ above given, by the length of the bay, and dividing the product by the distance between centers of bearings. The fourth root of the quotient will be the required diameter.

The following table is based upon the above rule, and is substantially correct:

Diameter of Shaft given by the Formulæ for Head Shafts	Diameter of Shaft necessary to carry the Load at the Center of a Bay, which is from Center to Center of Bearings.							
	2½ ft	3 ft.	3½ ft.	4 ft.	5 ft.	6 ft.	8 ft.	10 ft.
In.	In.	In.	In.	In.	In.	In.	In.	In.
2	2⅛	2¼	2⅜	2½	2⅝	2¾	2⅞	3
2½	2½	2⅝	2¾	2⅞	3	3⅛	3⅜	3⅝
3	3	3⅛	3¼	3⅜	3½	3¾	4	4¼
3½	...	3½	3⅝	3¾	4	4¼	4½	4¾
4	...	4	4⅛	4¼	4½	4¾	5⅛	5⅜
4½	...	...	4½	4⅝	4⅞	5⅛	5½	5⅞
5	...	...	5	5⅛	5⅜	5⅝	6	6¼
5½	...	...	...	5½	5¾	6	6½	6⅞
6	...	...	...	6	6⅜	6⅝	7⅛	7½

Should the load be placed near one end of the bay, multiply the fourth power of the diameter of shaft necessary to safely carry the load at the center of the bay (see above table) by the product of the two ends of the shaft, and divide this product by the product of the two ends of the shaft where the pulley is placed in the center. The fourth root of this quotient will be the required diameter.

A shaft carrying both receiving and driving pulleys should be figured as a head-shaft.

Deflection of Shafting

As the deflection of steel and iron is practically alike under similar conditions of dimensions and loads, and as shafting is usually determined by its transverse stiffness rather than its ultimate strength, nearly the same dimensions should be used for steel as for iron.

For continuous line shafting it is considered good practice to limit the deflection to a maximum of 1-100 of an inch per foot of length. The weight of bare shafting in pounds $= 2.6\ d^2L = W$, or when as fully loaded with pulleys as is customary in practice, and allowing 40 pounds per inch of width for the vertical pull of the belts, experience shows the load in pounds to be about $13\ d^2L = W$.

Taking the modulus of transverse elasticity at 26,000,000 pounds, we derive from authoritative formulæ the following:

$$L = \sqrt[3]{873\, d^2},\quad d = \sqrt{\frac{L^3}{873}},\ \text{for bare shafting:}$$

$$L = \sqrt[3]{175\, d^2},\quad d = \sqrt{\frac{L^3}{175}},\ \text{for shafting carrying pulleys, etc.:}$$

L being the maximum distance in feet between bearings for continuous shafting subjected to bending stress alone, d = diam. in inches.

The torsional stress is inversely proportional to the velocity of rotation, while the bending stress will not be reduced in the same ratio. It is therefore impossible to write a formula covering the whole problem and sufficiently simple for practical application, but the following rules are correct within the range of velocities usual in practice.

For continuous shafting so proportioned as to deflect not more than 1-100 of an inch per foot of length, allowance being made for the weakening effect of key-seats,

$$d = \sqrt[3]{\frac{50\ h.\ p.}{r}},\quad L = \sqrt[3]{700\, d^2}\ \text{for bare shafts;}$$

$$d = \sqrt[3]{\frac{70\ h.\ p.}{r}},\quad L = \sqrt[3]{140 d^2}\ \text{for shafts carrying pulleys, etc.}$$

d = diameter in inches: L = length in feet: r = revolutions per minute.

The following table (by J. B. Francis) gives the greatest admissible distances between the bearings of continuous shafts subject to no transverse strain, except from their own weight.

Diameter of Shaft in Inches	Distance Between Bearings in Feet		Diameter of Shaft in Inches	Distance Between Bearings in Feet	
	Wrought Iron Shafts	Steel Shafts		Wrought Iron Shafts	Steel Shafts
2	15.46	15.89	6	22.30	22.92
3	17.70	18.19	7	23.48	24.13
4	19.48	20.02	8	24.55	25.23
5	20.99	21.57	9	25.58	26.24

The writer prefers to apply a formula in all cases rather than use tables, as shafting is nearly always 1/16 inch less in diameter than the sizes quoted. The following tables are made up from the formulæ first given in this chapter.

Horsepower Transmitted by Turned Iron Shafting
As Prime Mover or Head Shaft Well Supported by Bearings

Diam.	Revolutions per Minute										
	60	80	100	125	150	175	200	225	250	275	300
Ins.	h. p.	h. p.	h. p.	h. p.	h. p.	h. p.	h. p.	h. p.	h. p.	h. p.	h. p.
1¾	2.6	3.4	4.3	5.4	6.4	7.5	8.6	9.7	10.7	11.8	12.9
2	3.8	5.1	6.4	8	9.6	11.2	12.8	14.4	16	17.6	19.2
2¼	5.4	7.3	8.1	10	12	14	16	18	20	22	24
2½	7.5	10	12.5	15	18	22	25	28	31	34	37
2¾	10	13	16	20	24	28	32	36	40	44	48
3	13	17	20	25	30	35	40	45	50	55	60
3¼	16	22	27	34	40	47	54	61	67	74	81
3½	20	27	34	42	51	59	68	76	85	93	102
3¾	25	33	42	52	63	73	84	94	105	115	126
4	30	41	51	64	76	89	102	115	127	140	153
4½	43	58	72	90	108	126	144	162	180	198	216
5	60	80	100	125	150	175	200	225	250	275	300
5½	80	106	133	166	199	233	266	299	333	366	400

Approximate Centers of Bearings for Wrought Iron Line Shafts Carrying a Fair Proportion of Pulleys

Shaft, Diameter Inches.....	1½	1¾	2	2¼	2½	2¾	3	3½	4	4½
c. to c. Bearings—Feet......	7	7½	8	8¾	9	9½	10	11	12	13
Shaft, Diameter Inches.....	5	5½	6	6½	7	7½	8	9	10	
c. to c. Bearings—Feet......	13½	14	15	15½	16	17	18	19	20	

Horsepower Transmitted by Cold-rolled Iron Shafting
As Prime Mover or Head Shaft Well Supported by Bearings

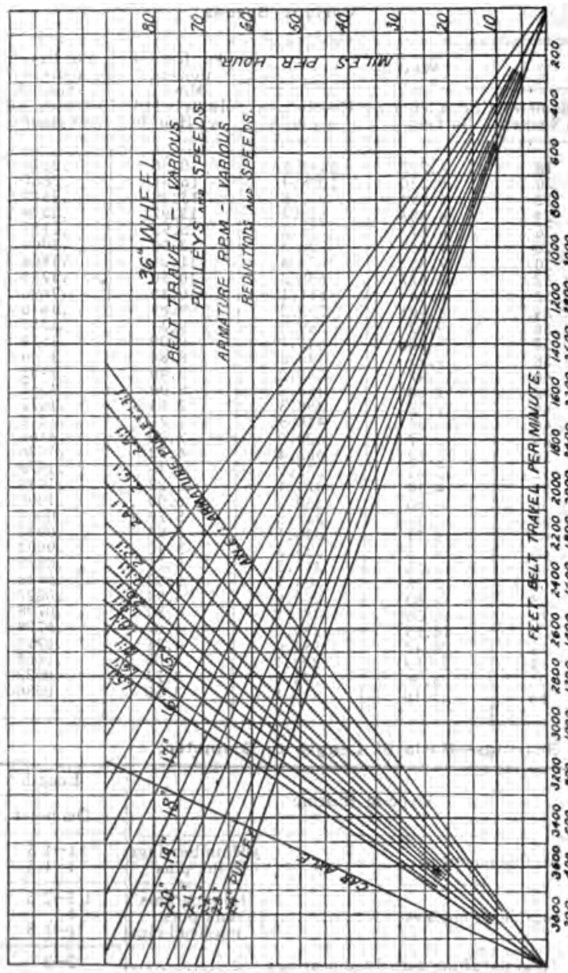
Diam.	Revolutions per Minute										
	60	80	100	125	150	175	200	225	250	275	300
Ins.	h.p.	h.p.	h.p.	h.p.	h.p.	h.p.	h.p.	h.p.	h.p.	h. p.	h.p.
1½	2.7	3.6	4.5	5.6	6.7	7.9	9.0	10	11	12	13
1¾	4.3	5.6	7.1	8.9	10.6	12.4	14.2	16	18	19	21
2	6.4	8.5	10.7	13	16	19	21	24	26	29	32
2¼	9	12	15	19	23	26	30	34	38	42	46
2½	12	17	21	26	31	36	41	47	52	57	62
2¾	16	22	27	35	41	48	55	62	70	76	82
3	21	29	36	45	54	63	72	81	90	98	108
3¼	27	36	45	57	68	80	91	103	114	126	136
3½	34	45	57	71	86	100	114	129	142	157	172
3¾	42	56	70	87	105	123	140	158	174	193	210
4	51	69	85	106	128	149	170	192	212	244	256
4½	73	97	121	151	182	212	243	273	302	333	364

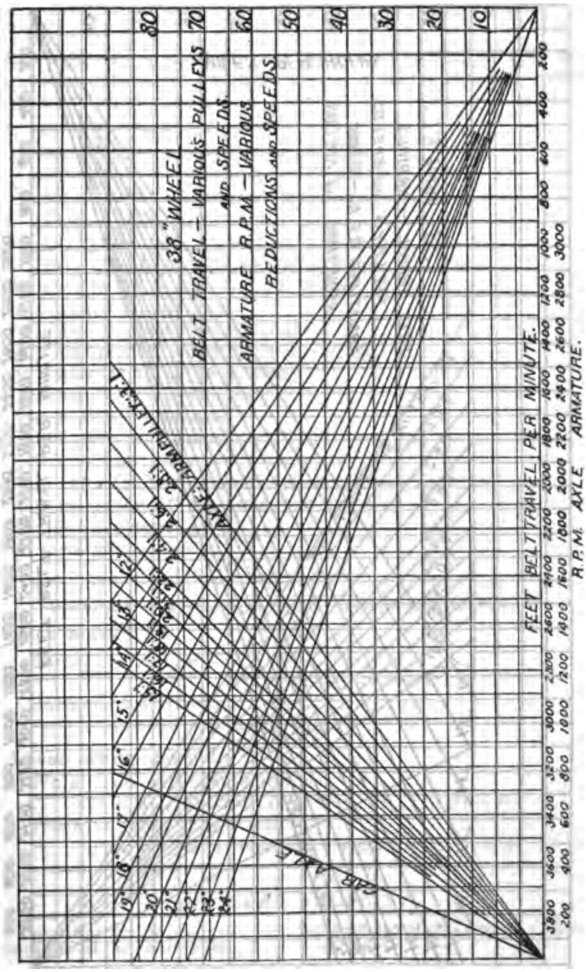
Revolutions of Wheels Per Minute and Per Second at Various Speeds

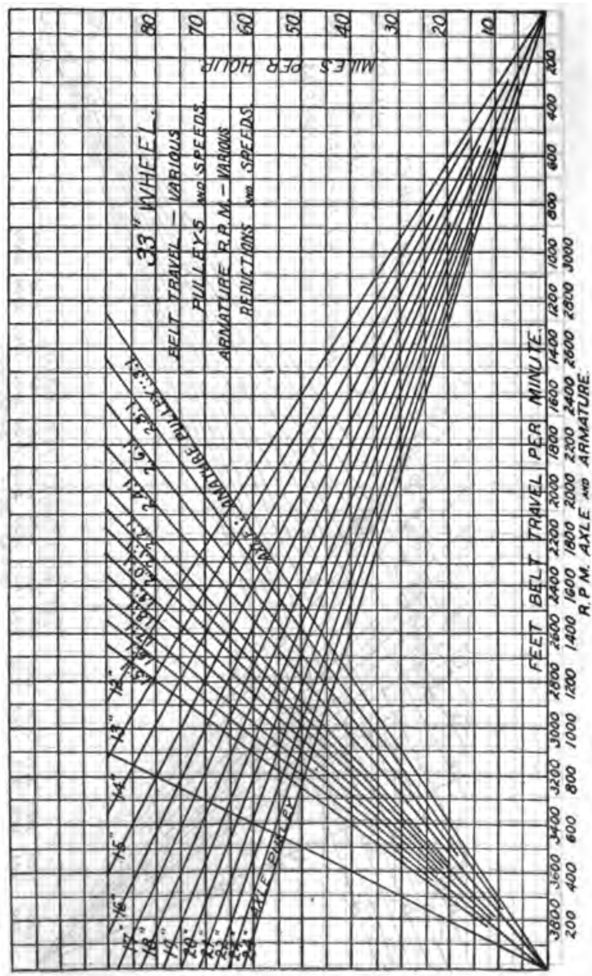
Wheels			For Revolutions per Minute Multiply Miles per Hour by	For Revolutions per Second Multiply Miles per Hour by
Diameter in Inches	Circumference in Feet	Revolutions per Mile		
18	4.712	1119.76	18.66	.3110
20	5.236	1008.4	16.81	.2801
22	5.759	916.8	15.28	.2547
24	6.283	838.4	13.97	.2329
26	6.81	775.3	12.92	.2153
28	7.36	720.3	12.00	.2000
30	7.85	672.6	11.21	.1868
32	8.377	630.3	10.50	.1751
33	8.64	611.1	10.18	.1696
34	8.901	593.2	9.89	.1648
36	9.42	560.5	9.34	.1556
37	9.686	545.1	9.09	.1514
38	9.95	530.6	8.84	.1440
40	10.47	504.2	8.40	.1401
42	11.00	480.0	8.00	.1363
44	11.52	458.3	7.64	.1273
46	12.04	438.5	7.31	.1218
48	12.57	420.0	7.00	.1166
50	13.00	403.4	6.72	.1120
52	13.61	387.9	6.46	.1073
54	14.14	373.4	6.22	.1033
56	14.66	360.2	6.00	.1000
58	15.18	347.8	5.79	.0965
60	15.71	336.1	5.60	.0933
62	16.23	325.3	5.42	.0903
64	16.75	315.2	5.25	.0875
66	17.28	305.5	5.09	.0848
68	17.80	296.6	4.94	.0822
70	18.36	288.1	4.80	.0798
72	18.85	280.1	4.67	.0778
78	20.42	258.6	4.31	.0718
84	21.99	240.1	4.00	.0666
90	23.56	224.1	3.73	.0622
96	25.16	210.1	3.50	.0586

Bearings—Ratio of Length to Diameter:

Type of Bearing		Length / Diameter
Marine engine	Main bearings	1—1.5
	Crank pins	1—1.5
Stationary engines	Main journals	1.5—2.5
	Crank pins	1—
	Crosshead pins	1—1.5
Heavy shafting with fixed bearings		2—3
Ordinary shafting—self-adjusting bearings		3—4
Generator bearings		3


36" WHEEL
BELT TRAVEL – VARIOUS PULLEYS AND SPEEDS
ARMATURE R.P.M. – VARIOUS REDUCTIONS AND SPEEDS
MILES PER HOUR
80
70
60
50
40
30
20
10
FEET BELT TRAVEL PER MINUTE
R.P.M. – AXLE AND ARMATURE
3800 3600 3400 3200 3000 2800 2600 2400 2200 2000 1800 1600 1400 1200 1000 800 600 400 200
200 400 600 800 1000 1200 1400 1600 1800 2000 2200 2400 2600 2800 3000
CAR AXLE
PULLEYS
20" 19" 18" 17" 16" 15"
ARMATURE


38" WHEEL
BELT TRAVEL — VARIOUS PULLEYS AND SPEEDS
ARMATURE R.P.M. — VARIOUS REDUCTIONS AND SPEEDS
FEET BELT TRAVEL PER MINUTE.
R.P.M. AXLE ARMATURE.
CAR AXLE


33" WHEEL.
BELT TRAVEL — VARIOUS PULLEYS AND SPEEDS.
ARMATURE R.P.M. — VARIOUS REDUCTIONS AND SPEEDS.
MILES PER HOUR
FEET BELT TRAVEL PER MINUTE.
R.P.M. AXLE AND ARMATURE.
AXLE PULLEY
ARMATURE PULLEY

Friction: There are two main divisions under the heading of friction:

A. Friction of rest, occurring when a body is about to start.

B. Friction of motion, less than the friction of rest and occurring when two bodies are in relative motion. This kind of friction consists of

1. Sliding friction:
   (a) Bodies sliding on a surface.
   (b) Axles or journals revolving in boxes.
   (c) Pivots turning on steps.
2. Rolling friction:
   (a) One body rolling on a plane.
   (b) One body rolling on another not plane.

α = angle of inclination of plane.
ϕ = angle of friction.
θ = arc of contact of journal.
β = inclination of force with plane.
N = normal force on a plane.
f = coefficient of friction.
r = radius of journal.
l = length of journal.
n = r. p. m.
V = velocity of rubbing surface in feet per min.
p = intensity of pressure per sq. in.
P = total pressure.
W = weight of body.

USEFUL FORMULÆ FOR UNIFORM MOTION

On a Plane:

Force of friction

$$F = fN - N \tan \alpha = N \tan \phi$$

Coefficient of friction

$$f = \tan \alpha = \tan \phi = \sqrt{W^2 - N^2} \div N$$

Loose-fitting Journal:

Weight on journal (squared)

$$W^2 = N^2 + F^2 = N^2 \ (1 + f^2) = F^2 \ (1 + f^2) \div f^2$$

Work of friction per min.

$$U = FV - 2\pi nrW \sin\phi = 2\pi \, nrfW \div \sqrt{1 + f^2}$$

ANGULAR VELOCITY

The number of degrees per second through which a body revolves about a center.

$$w = 2 \ \pi \ n.$$

where

w = angular velocity.
n = revolutions per second.

Perfectly-fitting Journal:

Pressure per sq. in.

$$p = 0.64\ W\ \cos\theta \div 1r$$

Maximum pressure per sq. in.

$$pm = 0.64W \div 1r$$

Total force of friction

$$F = fP = 1.27\ fW$$

Work of friction per minute

$$U - FV - 1.27\ fWV = 2.54\ \pi fnrW$$

CENTRIFUGAL FORCE

F = centrifugal force in pounds.
W = weight in pounds.
v = velocity in feet per second.
r = radius of circle in feet.
n = revolutions per minute.

Then

$$F = \frac{W\ r\ n^2}{2933}.$$

SECTION XI

TABLES

INCLUDING TABLES OF WEIGHTS AND MEASURES, SPECIFIC GRAVITY, MULTIPLES, DECIMALS OF AN INCH, AREAS AND CIRCUMFERENCES OF CIRCLES, LOGARITHMS, TRIGONOMETRIC FUNCTIONS, SQUARES, CUBES, SQUARE ROOTS, CUBE ROOTS AND RECIPROCALS

WEIGHTS AND MEASURES

Troy Weight: 24 grains = 1 pwt.; 20 pwts. = 1 ounce; 12 ounces = 1 pound. Used for weighing gold, silver, and jewels.

Apothecaries' Weight: 20 grains = 1 scruple; 3 scruples = 1 dram, 8 drams = 1 ounce; 12 ounces = 1 pound. The ounce and pound in this are the same as in Troy Weight.

Avoirdupois Weight: 27 11-32 grains = 1 dram; 16 drams = 1 ounce; 16 ounces = 1 pound; 100 pounds = 1 cwt.; 2,000 pounds = 1 short ton; 2,240 pounds = 1 long ton.

1 oz. Troy = 480 gr.; 1 oz. Av. = 437½ gr.; 1 lb. Troy = 5,760 gr.; 1 lb. Av. = 7,000 gr.

Dry Measure: 2 pints = 1 quart; 8 quarts = 1 peck; 4 pecks = 1 bushel.

Liquid Measure: 4 gills = 1 pint; 2 pints = 1 quart; 4 quarts = 1 gallon; 31½ gallons = 1 barrel; 2 barrels = 1 hogshead. Barrels and hogsheads vary in size.

Time Measure: 60 seconds = 1 minute; 60 minutes = 1 hour; 24 hours = 1 day; 7 days = 1 week. 28, 29, 30 or 31 days = 1 calendar month (30) days = 1 month in computing interest); 365 days = 1 year; 366 days = 1 leap year.

Circular Measure: 60 seconds = 1 minute; 60 minutes = 1 degree; 30 degrees = 1 sign; 90 degrees = 1 quadrant; 4 quadrants = 12 signs, or 360 degrees = 1 circle.

Long Measure: 12 inches = 1 foot; 3 feet = 1 yard; 5½ yards = 1 rod; 40 rods = 1 furlong; 8 furlongs = 1 stat. mile; 3 miles = 1 league.

Mariners' Measure: 6 feet = 1 fathom; 120 fathoms = 1 cable length; 7⅓ cable lengths = 1 mile; 5,280 feet = 1 stat. mile; 6,085 feet = 1 naut. mile.

Miscellaneous: 4 inches = 1 hand; 18 inches = 1 cubit; 21.8 inches = 1 Bible cubit; 2½ feet = 1 military pace.

Square Measure: 144 sq. inches = 1 sq. foot; 9 sq. feet = 1 square yard; 30¼ sq. yards = 1 sq. rod; 40 sq. rods = 1 rood; 4 roods = 1 acre; 640 acres = 1 sq. mile.

Surveyors' Measure: 7.92 inches = 1 link; 25 links = 1 rod; 4 rods = 1 chain; 10 sq. chains or 160 sq. rods = 1 acre; 640 acres = 1 sq. mile or section; 36 sq. miles (6 miles square) = 1 township.

Cubic Measure: 1,728 cubic inches = 1 cubic foot; 27 cubic feet = 1 cubic yard; 2,150.42 cubic inches = 1 standard bushel; 231 cubic inches = 1 standard gallon; 1 cubic foot = about four-fifths of a bushel; 128 cubic feet = 1 cord (wood); 40 cubic feet = 1 ton (shipping).

Metric Equivalents: Linear—1 centimeter = 0.3937 inches; 1 decimeter = 3.937 inches = 0.328 ft.; 1 meter = 39.37 inches = 1.0936 yards; 1 dekameter = 1.9884 rods; 1 kilometer = 0.62137 mile.

Square—1 sq. centimeter = 0.1550 sq. in.; 1 sq. decimeter = 0.1076 sq. ft.; 1 sq. meter = 1.196 sq. yds.; 1 are = 3,954 sq. rds.; 1 hektar = 2.47 acres; 1 sq. kilometer = 0.386 sq. mile.

Volume—1 cubic centimeter = 0.061 cubic in.; 1 cubic decimeter = 0.0353 cubic ft.; 1 cubic meter, 1 ster = 1.308 cubic yds., 0.2759 cd.; 1 liter = 0.908 qt. dry, 1.0567 qts. liq.; 1 dekaliter = 2.6417 gals., .135 peck; 1 hektoliter = 2.8375 bus.

Weights: 1 gram = 0.03527 ounce; 1 kilogram = 2.2046 lbs.; 1 metric ton = 1.1023 English tons.

Approximate Metric Equivalents: 1 decimeter = 4 inches; 1 meter = 1.1 yards; 1 kilometer = 5/8 of mile; 1 hektar = 2½ acres; 1 ster, or cubic meter = ¼ of a cord; 1 liter = 1.06 qts. liquid, 0.9 qt. dry; 1 hektoliter = 2⅝ bushels; 1 kilogram = 2 1-5 lbs.; 1 metric ton = 2,200 lbs.

THE METRIC SYSTEM

The metric system is used in scientific work in all countries, and in business by all civilized nations except the English-speaking peoples.

The **meter** is the base of the system, being (nearly) one ten-millionth of the distance from the equator to the pole.

A **gram** is the weight of a cube of water at its greatest density, having an edge of .01 meter.

A **liter** is the contents of a cube having an edge of .1 meter.

Are, 100 sq. meters; and **stere**, 1 cu. meter, are seldom used.

The prefixes used with the units of measure signify as follows:

Mikro	.000001	Deka	10
Milli	.001	Hekto	100
Centi	.01	Kilo	1,000
Deci	.1	Myria	10,000

Table of Length

1 mikron	= .000001	of a meter
1 millimeter (mm)	= .001	of a meter
1 centimeter (cm)	= .01	of a meter
1 decimeter (dm)	= .1	of a meter

Meter (m)

1 dekameter	= 10 meters
1 hektometer	= 100 meters
1 kilometer	= 1,000 meters
1 myriameter	= 10,000 meters

Table of Square Measure

1 sq. millimeter	= .000001	of a sq. meter
1 sq. centimeter	= .0001	of a sq. meter
1 sq. decimeter	= .01	of a sq. meter

Square meter

1 sq. dekameter (are)	= 100 sq. meters
1 sq. hektometer (hektare)	= 10,000 sq. meters
1 sq. kilometer	= 1,000,000 sq. meters
1 sq. myriameter	= 100,000,000 sq. meters

Table of Cubic Measure

1 cu. millimeter	= .000000001	of a cu. meter
1 cu. centimeter	= .000001	of a cu. meter
1 cu. decimeter	= .001	of a cu. meter

Cubic meter (stere)

1 cu. dekameter	= 1,000 cu. meters
1 cu. hektometer	= 1,000,000 cu. meters
1 cu. kilometer	= 1,000,000,000 cu. meters
1 cu. myriameter	= 1,000,000,000,000 cu. meters

Table of Weight

1 mikrogram	= .000001	of a gram
1 milligram (mg)	= .001	of a gram
1 centigram (cg)	= .01	of a gram
1 decigram (dg)	= .1	of a gram

Gram (g)

1 dekagram	= 10 grams
1 hektogram	= 100 grams
1 kilogram (kg)	= 1,000 grams
1 myriagram	= 10,000 grams
1 quintal (q)	= 100,000 grams
1 metric ton (t)	= 1,000,000 grams

A metric ton is the weight of one cubic meter of water.
A kilogram is the weight of one liter of water.

Table of Capacity

1 mikroliter	= .000001	of a liter
1 milliliter (mi)	= .001	of a liter
1 centiliter	= .01	of a liter
1 deciliter	= .1	of a liter

Liter (l)

1 dekaliter........ = 10 liters 1 hektoliter........ = 100 liters

SPECIFIC GRAVITIES AND WEIGHTS OF VARIOUS SUBSTANCES

The Basis for Specific Gravities is Pure Water at 62 Degrees Fah., Barometer 30 inches Weight of One Cubic Foot. 62.355 Pounds	Average Specific Gravity Water=1	Average Weight of 1 Cu. Ft. Pounds
Air, atmospheric at 60 degrees F., under pressure of one atmosphere, or 14.7 pounds per square inch, weighs 1-815th as much as water	.00123	.0765
Aluminum	2.6	162
Anthracite, 1.3 to 1.84; of Penn., 1.3 to 1.7	1.5	93.5
Anthracite, broken, of any size, loose	....	52—56
Anthracite, broken, moderately shaken	....	56—60
Anthracite, broken, heaped bushel, loose, 77 to 83 pounds	....	....
Anthracite, broken, a ton loose occupies 40 to 43 cubic feet	....	....
Antimony, cast	6.70	418
Antimony, native	6.67	416
Ash, perfectly dry (see note)	.752	47
Ash, American white dry (see note)	.61	38
Ashes of soft coal, solidly packed	....	40—45
Asphaltum, 1 to 1.8	1.4	87.3
Brass (copper and zinc) cast 7.8 to 8.4	8.1	504
Brass, rolled	8.4	524
Brick, best pressed	....	150
Brick, common and hard	....	125
Brick, soft inferior	....	100

Note—Green timbers usually weigh from one-fifth to nearly one-half more than dry; ordinary building timbers, tolerably seasoned, one-sixth more.

SPECIFIC GRAVITIES AND WEIGHTS OF VARIOUS SUBSTANCES—Continued

The Basis for Specific Gravities is Pure Water at 62 Degrees Fah., Barometer 30 Inches Weight of One Cubic Foot, 62.355 Pounds	Average Specific Gravity Water=1	Average Weight 1 Cu. Ft. Pounds
Brickwork, pressed brick, fine joints	....	140
" medium quality	....	125
" coarse, inferior, soft	....	100
" at 125 pounds per cubic foot, 1 cubic yard equals 1.507 tons, and 17.92 cubic feet equal 1 ton	....	....
Bronze, copper 8, tin 1 (gun metal)	8.5	529
Cement, hydraulic, American, Rosendale, ground and loose	....	56
" hydraulic, American, Rosendale, U. S. struck bush, 70 pounds	....	....
" hydraulic, American, Rosendale, Louisville bushel 62 pounds	....	....
" hydraulic, American, Cumberland, ground, loose	....	65
" hydraulic, American, Cumberland, ground, thoroughly shaken	....	85
" hydraulic, English Portland (U. S. struck bushel 100 to 128)	....	81—102
" hydraulic, English Portland, a barrel 400 to 430 pounds	....	....
" hydraulic, American Portland, loose	....	88
" hydraulic, American Portland, thoroughly shaken		110
Charcoal of pines and oaks	....	15—30
Chalk	2.5	156
Cherry, perfectly dry (see note)	.672	42
Chestnut, perfectly dry (see note)	.660	41
Clay, potters', dry, 1.8 to 2.1	1.9	119
" dry in lump, loose	....	63
Coal, bituminous, solid, 1.2 to 1.5	1.35	84
" " solid, Cambria Co., Pa., 1.27-1.34	....	79—84
" " broken, of any size, loose	....	47—52
" " moderately shaken	....	51—56
" " a heaped bushel, loose, 70 to 78	....	....
" " 1 ton occupies 43 to 48 cubic feet	....	....
Coke, loose, good quality	....	23—32
" loose, a heaped bushel, 35 to 42	....	....
" 1 ton occupies 80 to 97 cubic feet	....	....
Corundum, pure, 3.8 to 4	3.9	....
Copper, cast, 8.6 to 8.8	8.7	542
" rolled, 8.8 to 9	8.9	555
Cork, dry (see note)	.24	15
Cypress, American (see note)	.55	64
Earth, common loam, perfectly dry, loose	....	72—80
" " perfectly dry, shaken	....	82—92
" " perfectly dry, rammed	....	90—100
" " slightly moist, loose	....	70—76
" " more moist, loose	....	66—68
" " more moist, shaken	....	75—90

NOTE—Green timbers usually weigh from one-fifth to nearly one-half more than dry; ordinary building timbers, tolerably seasoned, one-sixth more.

SPECIFIC GRAVITIES AND WEIGHTS OF VARIOUS SUBSTANCES—Continued

The Basis for Specific Gravities is Pure Water at 62 Degrees Fah., Barometer 30 Inches Weight of One Cubic Foot, 62.355 Pounds	Average Specific Gravity Water=1	Average Weight 1 Cu. Ft. Pounds
Earth, common loam, more moist, packed	....	90—100
" " as soft flowing mud	....	104—112
" " as soft flowing mud well pressed	....	110—120
Elm, perfectly dry (see note)	.56	35
Flint	2.6	162
Glass, 2.5 to 3.45	2.98	186
" common window	2.52	157
Gneiss, common, 2.62 to 2.76	2.69	168
" in loose piles	....	96
Gold, cast, pure or 24 karat	19.258	1204
" pure, hammered	19.5	1217
Granite, 2.56 to 2.88	2.72	170
Greenstone, trap, 2.8 to 3.2	3.00	187
Gypsum, plaster of Paris, 2.24 to 2.30	2.27	141.6
Hemlock, perfectly dry (see note)	.4	25
Hickory, perfectly dry (see note)	.85	53
Ice, .917 to .922	.92	57.4
Iron, cast, 6.9 to 7.4	7.15	446
" gray foundry, cold	7.21	450
" gray foundry, molten	6.94	433
" wrought	7.69	480
Lead, commercial	11.38	709.6
Lignum vitæ (dry)	.65—1.33	41—83
Limestone and marbles	2.6	164.4
Lime, quick	1.5	95
" quick, ground, well shaken, per struck bushel 80 pounds	....	64
" quick, ground, thoroughly shaken, per struck bushel 93¾ pounds	....	75
Locust, dry (see note)	.71	44
Mahogany, Spanish, dry (see note)	.85	53
" Honduras, dry (see note)	.56	35
Maple, dry (see note)	.79	49
Marbles (see Limestone)		
Masonry of granite or limestone, well-dressed	....	165
" of granite, well-scabbled mortar rubble, about 1-5 of mass will be mortar	....	154
" of granite, well-scabbled dry rubble	....	138
" of granite, roughly scabbled mortar rubble, about ¼ to 1-3 of mass will be mortar	....	150
" of granite, scabbled dry rubble	....	125
" of sandstone, ⅛ less than granite	....	....
" of brickwork (see Brickwork)		
Mercury, at 32 degrees Fahr	13.62	849
Mica, 2.75 to 3.1	2.93	183
Mortar, hardened, 1.4 to 1.9	1.65	103
Mud, dry, close	....	80—110
" wet, moderately pressed	....	110—130
" wet, fluid	....	104—120
Oak, live, perfectly dry, .88—1.02 (see note)	.95	59.3

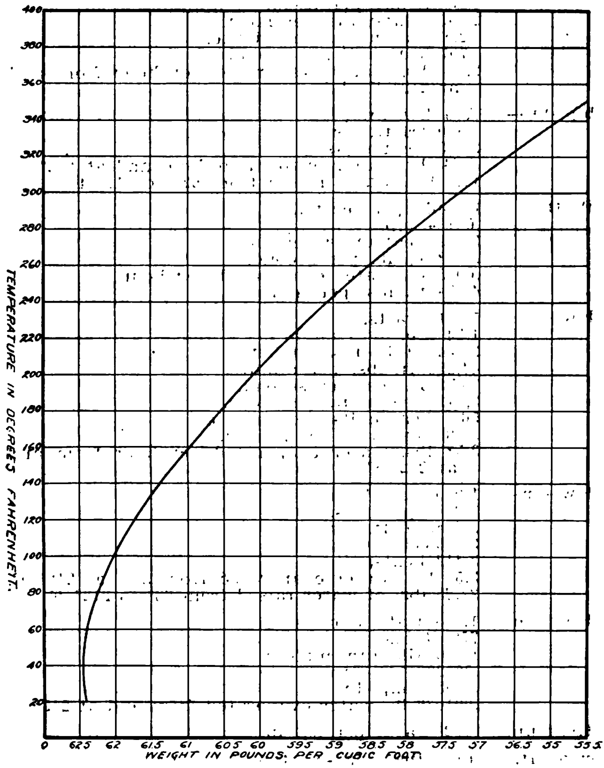
NOTE—Green timbers usually weigh from one-fifth to nearly one-half more than dry; ordinary building timbers, tolerably seasoned, one-sixth more.

SPECIFIC GRAVITIES AND WEIGHTS OF VARIOUS SUBSTANCES—Continued

The Basis for Specific Gravities is Pure Water at 62 Degrees Fah., Barometer 30 Inches. Weight of One Cubic Foot, 62.355 Pounds	Average Specific Gravity Water=1	Average Weight 1 Cu. Ft. Pounds
Oak, white, perfectly dry, .66 to .88 (see note)	.77	48
" red, black, perfectly dry	....	32—45
Petroleum	.878	54.8
Pine, white, perfectly dry, .35 to .45 (see note below)	.40	25
" yellow, Northern, perfectly dry, .48 to .62 (see note below)	.55	34.3
" yellow, Southern, perfectly dry, .64 to .8 (see note below)	.72	45
Pitch	1.15	71.7
Poplar, dry (see note below)	.47	29
Platinum	21.5	1342
Quartz	2.65	165
Rosin	1.10	68.6
Salt, coarse (per struck bushel, Syracuse, N. Y., 56 pounds)	....	45
Sand, of pure quartz, perfectly dry and loose	....	90—106
" " voids full of water	....	118—129
" " very large and small grains, dry	....	117
Sandstone, 2.1 to 2.73, 131 to 171	2.41	151
" quarried and piled, 1 measure solid makes 1¾ (about) piled	....	86
Snow, fresh fallen	....	5—12
" moistened, compacted by rain	....	15—50
Sycamore, perfectly dry (see note below)	.59	37
Shales, red or black, 2.4 to 2.8	2.6	162
Silver	10.5	655
Slate, 2.7 to 2.9	2.8	175
Soapstone, 2.65 to 2.8	2.73	170
Spruce, perfectly dry (see note below)	.4	25
Steel	7.85	490
Sulphur	2.00	125
Tallow	.94	58.6
Tar	1.	62.355
Tin, cast, 7.2 to 7.5	7.35	459
Walnut, black, perfectly dry (see note below)	.61	38
Water, pure rain, distilled, at 32 degrees F., Bar. 30 inches	....	62.417
" pure rain, distilled, at 62 degrees F., Bar. 30 inches	1	62.355
" pure rain, distilled, at 212 degrees F., Bar. 30 inches	....	59.7
" sea, 1.026 to 1.030	1.028	64.08
Zinc or spelter, 6.8 to 7.2	7.00	437.5

NOTE—Green timbers usually weigh from one-fifth to nearly one-half more than dry; ordinary building timbers, tolerably seasoned, one-sixth more.

WEIGHT OF WATER IN POUNDS PER CUBIC FOOT AT DIFFERENT TEMPERATURES.



USEFUL TABLES

Equivalent Value of Units

1 h.p.—	746 watts.
	.746 kilowatts.
	33,000 ft.-lbs. per minute.
	550 ft.-lbs. per second.
	2,545 heat-units per hour.
	42.4 heat-units per minute.
	.707 heat-unit per second.
	2.64 lbs. water evaporated per hour from and at 212° F.
1 h.p.-hr.—	.746 kw.-hrs.
	1,980,000 ft.-lbs.
	2.545 heat-units.
	2.64 lbs. water evaporated from and at 212° F.
	17.0 lbs. water raised from 62° to 212° F.
1 Watt—	1 joule per second.
	.00134 h.p.
	3,412 heat-units per hour.
	.7373 ft.-lb. per second.
	.0035 lb. water evaporated per hour.
	44.24 ft.-lbs. per minute.
1 Kw.—	1,000 watts.
	1.34 h.p.
	2,654,200 ft.-lbs. per hour.
	44,250 ft.-lbs. per minute.
	737.3 ft.-lbs. per second.
	3,412 heat-units per hour.
	56.9 heat-units per minute.
	.948 heat-unit per second.
	3.53 lbs. water evaporated per hour from and at 212° F.
1 Kw.-hr.—	1,000 watt-hours.
	1.34 h.p.-hours.
	2,654,200 ft.-lbs.
	3,600,000 joules.
	3,412 heat-units.
	3.53 lbs. water evaporated from and at 212° F.
	22.75 lbs. of water raised from 62° to 212° F.
1 Heat-unit—	1,055 watt seconds.
	778 ft. lbs.
	107.6 kilogram meters.
	.000293 kw.-hrs.
	.000393 h.p.-hr.
	.001036 lb. water evaporated from and at 212° F.
1 Heat-unit	.122 watts per sq. in.
per sq. ft.	.0176 kw. per sq. ft.
per minute —	0-236 h.p. per sq. ft.
1 Joule—	1 watt second.
	.000000278 kw.-hr.
	.0009477 heat-units.
	.7373 ft.-lb.
1 ft.-lb.—	1.356 joules.
	.000000377 Kw.-hrs.
	.001285 heat-units.
	.0000005 h.p.-hour.

TABLE OF MULTIPLES.

Diameter of a circle × 3.1416 = Circumference.

Radius of a circle × 6.283185 = Circumference.

Square of the radius of a circle × 3.1416 = Area.

Square of the diameter of a circle × 0.7854 = Area.

Square of the circumference of a circle × 0.07958 = Area.

Half the circumference of a circle × half its diameter = Area.

Circumference of a circle × 0.159155 = Radius.

Square root of the area of a circle × 0.56419 = Radius.

Circumference of a circle × 0.31831 = Diameter.

Square root of the area of a circle × 1.12838 = Diameter.

Diameter of a circle × 0.86 = Side of inscribed equilateral triangle.

Diameter of a circle × 0.7071 = Side of an inscribed square.

Circumference of a circle × 0.225 = Side of an inscribed square.

Circumference of a circle × 0.282 = Side of an equal square.

Diameter of a circle × 0.8862 = Side of an equal square.

Base of a triangle × ½ the altitude = Area.

Multiplying both diameters and .7854 together = Area of an ellipse.

Surface of a sphere × 1/6 of its diameter = Solidity.

Circumference of a sphere × its diameter = Surface.

Square of the diameter of a sphere × 3.1416 = Surface.

Square of the circumference of a sphere × 0.3183 = Surface.

Cube of the diameter of a sphere × 0.5236 = Solidity.

Cube of the radius of a sphere × 4.1888 = Solidity.

Cube of the circumference of a sphere × 0.016887 = Solidity.

Square root of the surface of a sphere × 0.56419 = Diameter.

Square root of the surface of a sphere × 1.772454 = Circumference.

Cube root of the solidity of a sphere × 1.2407 = Diameter.

Cube root of the solidity of a sphere × 3.8978 = Circumference.

Radius of a sphere × 1.1547 = Side of inscribed cube.

Square root of (1-3 of the square of) the diameter of a sphere = Side of inscribed cube.

Area of its base × 1-3 of its altitude = Solidity of a cone or pyramid, whether round, square or triangular.

Area of one of its sides × 6 = the surface of a cube.

Altitude of trapezoid × ½ the sum of its parallel sides = Area.

DECIMALS OF AN INCH FOR EACH 1-64TH

$\frac{1}{32}$ds	$\frac{1}{64}$ths	Decimal	Fraction	$\frac{1}{32}$ds	$\frac{1}{64}$ths	Decimal	Fraction
	1	.015625			33	.515625	
1	2	.03125		17	34	.53125	
	3	.046875			35	.546875	
2	4	.0625	$\frac{1}{16}$	18	36	.5625	$\frac{9}{16}$
	5	.078125			37	.578125	
3	6	.09375		19	38	.59375	
	7	.109375			39	.609375	
4	8	.125	⅛	20	40	.625	⅝
	9	.140625			41	.640625	
5	10	.15625		21	42	.65625	
	11	.171875			43	.671875	
6	12	.1875	$\frac{3}{16}$	22	44	.6875	$\frac{11}{16}$
	13	.203125			45	.703125	
7	14	.21875		23	46	.71875	
	15	.234375			47	.734375	
8	16	.25	¼	24	48	.75	¾
	17	.265625			49	.765625	
9	18	.28125		25	50	.78125	
	19	.296875			51	.796875	
10	20	.3125	$\frac{5}{16}$	26	52	.8125	$\frac{13}{16}$
	21	.328125			53	.828125	
11	22	.34375		27	54	.84375	
	23	.359375			55	.859375	
12	24	.375	⅜	28	56	.875	⅞
	25	.390625			57	.890625	
13	26	.40625		29	58	.90625	
	27	.421875			59	.921875	
14	28	.4375	$\frac{7}{16}$	30	60	.9375	$\frac{15}{16}$
	29	.453125			61	.953125	
15	30	.46875		31	62	.96875	
	31	.484375			63	.984375	
16	32	.5	½	32	64	1.	1

CIRCUMFERENCES AND AREAS OF CIRCLES FROM 1-64th TO 42

Diam.	Circum.	Area.	Diam.	Circum.	Area
1/64	.04909	.000192	6.	18.8496	28.2744
1/32	.09818	.000767	.⅛	19.2423	29.4648
1/16	.19635	.003068	.¼	19.635	30.6797
⅛	.3927	.012272	.⅜	20.0277	31.9191
3/16	.589	.027612	.½	20.4204	33.1831
¼	.7854	.049087	.⅝	20.8131	34.4717
5/16	.98175	.076699	.¾	21.2058	35.7848
⅜	1.1781	.110447	.⅞	21.5985	37.1224
7/16	1.37445	.15033	7.	21.9912	38.4846
½	1.5708	.19635	.⅛	22.3839	39.8713
9/16	1.76715	.248505	.¼	22.7766	41.2826
⅝	1.9635	.306796	.⅜	23.1693	42.7184
11/16	2.15985	.371224	.½	23.562	44.1787
¾	2.3562	.441787	.⅝	23.9547	45.6636
13/16	2.55255	.518487	.¾	24.3474	47.1731
⅞	2.7489	.601322	.⅞	24.7401	48.7071
15/16	2.94525	.690292	8.	25.1328	50.2656
1.	3.1416	.7854	.⅛	25.5255	51.8487
.⅛	3.5343	.99402	.¼	25.9182	53.4563
.¼	3.927	1.2272	.⅜	26.3109	55.0884
.⅜	4.3197	1.4849	.½	26.7036	56.7451
.½	4.7124	1.7671	.⅝	27.0963	58.4264
.⅝	5.1051	2.0739	.¾	27.489	60.1322
.¾	5.4978	2.4053	.⅞	27.8817	61.8625
.⅞	5.8905	2.7612	9.	28.2744	63.6174
2.	6.2832	3.1416	.⅛	28.6671	65.3968
.⅛	6.6759	3.5466	.¼	29.0598	67.2008
.¼	7.0686	3.9761	.⅜	29.4525	69.0293
.⅜	7.4613	4.4301	.½	29.8452	70.8823
.½	7.854	4.9087	.⅝	30.2379	72.7599
.⅝	8.2467	5.4119	.¾	30.6306	74.6621
.¾	8.6394	5.9396	.⅞	31.0233	76.5888
.⅞	9.0321	6.4918	10.	31.416	78.54
3.	9.4248	7.0686	.⅛	31.8087	80.5158
.⅛	9.8175	7.6699	.¼	32.2014	82.5161
.¼	10.2102	8.2958	.⅜	32.5941	84.5409
.⅜	10.6029	8.9462	.½	32.9868	86.5903
.½	10.9956	9.6211	.⅝	33.3795	88.6643
.⅝	11.3883	10.3206	.¾	33.7722	90.7628
.¾	11.781	11.0447	.⅞	34.1649	92.8858
.⅞	12.1737	11.7933	11.	34.5576	95.0334
4.	12.5664	12.5664	.⅛	34.9503	97.2055
.⅛	12.9591	13.3641	.¼	35.343	99.4022
.¼	13.3518	14.1863	.⅜	35.7357	101.6234
.⅜	13.7445	15.033	.½	36.1284	103.8691
.½	14.1372	15.9043	.⅝	36.5211	106.1394
.⅝	14.5299	16.8002	.¾	36.9138	108.4343
.¾	14.9226	17.7206	.⅞	37.3065	110.7537
.⅞	15.3153	18.6655	12.	37.6992	113.098
5.	15.708	19.635	.⅛	38.0919	115.466
.⅛	16.1007	20.629	.¼	38.4846	117.859
.¼	16.4934	21.6476	.⅜	38.8773	120.277
.⅜	16.8861	22.6907	.½	39.27	122.719
.½	17.2788	23.7583	.⅝	39.6627	125.185
.⅝	17.6715	24.8505	.¾	40.0554	127.677
.¾	18.0642	25.9673	.⅞	40.4481	130.192
.⅞	18.4569	27.1086	13.	40.8408	132.733

PROPERTIES OF LOGARITHMS

The exponent of the power to which a fixed number, called the **Base**, must be raised in order to produce a given number is called the **Logarithm** of the given number.

When 10 is the base, the logarithm of 100 is 2, for $100 = 10^2$; the logarithm of 1000 is 3, for $1000 = 10^3$.

Any number except unity may be used as the base of a system of logarithms, but 10 is the base of the **Common** or **Briggs** system.

Another or modified system is frequently employed in the mathematics and is known as the **Natural, Hyperbolic** or **Napierian** system. The base of this system is 2.7183, designated as "e."

The following relation holds between the **Common** and **Napierian** systems:

$$\log_e x = 2.3026 \log_{10} x$$

The integral part of a logarithm is called the **Characteristic**; the fractional or decimal part, the **Mantissa**.

The characteristic of the logarithm of a number greater than 1 is positive and 1 less than the number of digits in its integral part.

$$\text{Thus,} \quad \log 4580 = 3.6609$$
$$\text{That is,} \quad 4580 = 10^{3.6609}$$

The characteristic of the logarithm of a decimal is negative and numerically 1 greater than the number of ciphers immediately following the decimal point.

$$\text{Thus,} \quad \log .00458 = \bar{3}.6609$$
$$\text{That is,} \quad .00458 = 10^{-3} + .6609$$

To avoid writing a negative characteristic before a positive mantissa, it is customary to add 10 to the characteristic and indicate that this number is to be subtracted from the whole logarithm.

$$\text{Thus } \log .00458 = \bar{3}.6609 = 7.6609 - 10$$

(1) The logarithm of the product of any number of factors is equal to the sum of the logarithms of the individual factors.

$$\log MN = \log M + \log N$$

(2) The logarithm of the quotient of any two numbers is equal to the logarithm of the numerator diminished by the logarithm of the denominator.

$$\log \frac{M}{N} = \log M - \log N$$

(3) The logarithm of the r^{th} power of a number is equal to r times the logarithm of the number.

$$\log M^r = r \log M.$$

(4) The logarithm of the r^{th} root of a number is equal to $\frac{1}{r^{th}}$ of the logarithm of the number.

$$\log \sqrt[r]{M} = \frac{1}{r} \log M.$$

LOGARITHMS OF NUMBERS, FROM 0 TO 1000

No.	0	1	2	3	4	5	6	7	8	9
0	0	00000	30103	47712	60206	69897	77815	84510	90309	95424
10	00000	00432	00860	01283	01703	02118	02530	02938	03342	03742
11	04139	04532	04921	05307	05690	06069	06445	06818	07188	07554
12	07918	08278	08636	08990	09342	09691	10037	10380	10721	11059
13	11394	11727	12057	12385	12710	13033	13353	13672	13987	14301
14	14613	14921	15228	15533	15836	16136	16435	16731	17026	17318
15	17609	17897	18184	18469	18752	19033	19312	19590	19865	20139
16	20412	20682	20951	21218	21484	21748	22010	22271	22530	22788
17	23045	23299	23552	23804	24054	24303	24551	24797	25042	25285
18	25527	25767	26007	26245	26481	26717	26951	27184	27415	27646
19	27875	28103	28330	28555	28780	29003	29225	29446	29666	29885
20	30103	30319	30535	30749	30963	31175	31386	31597	31806	32014
21	32222	32428	32633	32838	33041	33243	33445	33646	33845	34044
22	34242	34439	34635	34830	35024	35218	35410	35602	35793	35983
23	36173	36361	36548	36735	36921	37106	37291	37474	37657	37839
24	38021	38201	38381	38560	38739	38916	39093	39269	39445	39619
25	39794	39967	40140	40312	40483	40654	40824	40993	41162	41330
26	41497	41664	41830	41995	42160	42324	42488	42651	42813	42975
27	43136	43296	43456	43616	43775	43933	44090	44248	44404	44560
28	44716	44870	45024	45178	45331	45484	45636	45788	45939	46089
29	46240	46389	46538	46686	46834	46982	47129	47275	47421	47567
30	47712	47856	48000	48144	48287	48430	48572	48713	48855	48995
31	49136	49276	49415	49554	49693	49831	49968	50105	50242	50379
32	50515	50650	50785	50920	51054	51188	51321	51454	51587	51719
33	51851	51982	52113	52244	52374	52504	52633	52763	52891	53020
34	53148	53275	53402	53529	53655	53781	53907	54033	54157	54282
35	54407	54530	54654	54777	54900	55022	55145	55266	55388	55509
36	55630	55750	55870	55990	56110	56229	56348	56466	56584	56702
37	56820	56937	57054	57170	57287	57403	57518	57634	57749	57863
38	57978	58092	58206	58319	58433	58546	58658	58771	58883	58995
39	59106	59217	59328	59439	59549	59659	59769	59879	59988	60097
40	60206	60314	60422	60530	60638	60745	60853	60959	61066	61172
41	61278	61384	61489	61595	61700	61804	61909	62013	62118	62221
42	62325	62428	62531	62634	62736	62838	62941	63042	63144	63245
43	63347	63447	63548	63648	63749	63848	63948	64048	64147	64246
44	64345	64443	64542	64640	64738	64836	64933	65030	65127	65224
45	65321	65417	65513	65609	65705	65801	65896	65991	66086	66181
46	66276	66370	66464	66558	66651	66745	66838	66931	67024	67117
47	67210	67302	67394	67486	67577	67669	67760	67851	67942	68033
48	68124	68214	68304	68394	68484	68574	68663	68752	68842	68930
49	69020	69108	69196	69284	69372	69460	69548	69635	69722	69810
50	69897	69983	70070	70156	70243	70329	70415	70500	70586	70671
51	70757	70842	70927	71011	71096	71180	71265	71349	71433	71516
52	71600	71683	71767	71850	71933	72015	72098	72181	72263	72345
53	72428	72509	72591	72672	72754	72835	72916	72997	73078	73158
54	73239	73319	73399	73480	73559	73639	73719	73798	73878	73957

LOGARITHMS OF NUMBERS, FROM 0 TO 1000 (Continued)

No.	0	1	2	3	4	5	6	7	8	9
55	74036	74115	74193	74272	74351	74429	74507	74585	74663	74741
56	74818	74896	74973	75050	75127	75204	75281	75358	75434	75511
57	75587	75663	75739	75815	75891	75966	76042	76117	76192	76267
58	76342	76417	76492	76566	76641	76715	76789	76863	76937	77011
59	77085	77158	77232	77305	77378	77451	77524	77597	77670	77742
60	77815	77887	77959	78031	78103	78175	78247	78318	78390	78461
61	78533	78604	78675	78746	78816	78887	78958	79028	79098	79169
62	79239	79309	79379	79448	79518	79588	79657	79726	79796	79865
63	79934	80002	80071	80140	80208	80277	80345	80413	80482	80550
64	80618	80685	80753	80821	80888	80956	81023	81090	81157	81224
65	81291	81358	81424	81491	81557	81624	81690	81756	81822	81888
66	81954	82020	82085	82151	82216	82282	82347	82412	82477	82542
67	82607	82672	82736	82801	82866	82930	82994	83058	83123	83187
68	83250	83314	83378	83442	83505	83569	83632	83695	83758	83821
69	83884	83947	84010	84073	84136	84198	84260	84323	84385	84447
70	84509	84571	84633	84695	84757	84818	84880	84941	85003	85064
71	85125	85187	85248	85309	85369	85430	85491	85551	85612	85672
72	85733	85793	85853	85913	85973	86033	86093	86153	86213	86272
73	86332	86391	86451	86510	86569	86628	86687	86746	86805	86864
74	86923	86981	87040	87098	87157	87215	87273	87332	87390	87448
75	87506	87564	87621	87679	87737	87794	87852	87909	87966	88024
76	88081	88138	88195	88252	88309	88366	88422	88479	88536	88592
77	88649	88705	88761	88818	88874	88930	88986	89042	89098	89153
78	89209	89265	89320	89376	89431	89487	89542	89597	89652	89707
79	89762	89817	89872	89927	89982	90036	90091	90145	90200	90254
80	90309	90363	90417	90471	90525	90579	90633	90687	90741	90794
81	90848	90902	90955	91009	91062	91115	91169	91222	91275	91328
82	91381	91434	91487	91540	91592	91645	91698	91750	91803	91855
83	91907	91960	92012	92064	92116	92168	92220	92272	92324	92376
84	92427	92479	92531	92582	92634	92685	92737	92788	92839	92890
85	92941	92993	93044	93095	93146	93196	93247	93298	93348	93399
86	93449	93500	93550	93601	93651	93701	93751	93802	93852	93902
87	93951	94001	94051	94101	94151	94200	94250	94300	94349	94398
88	94448	94497	94546	94596	94645	94694	94743	94792	94841	94890
89	94939	94987	95036	95085	95133	95182	95230	95279	95327	95376
90	95424	95472	95520	95568	95616	95664	95712	95760	95808	95856
91	95904	95951	95999	96047	96094	96142	96189	96236	96284	96331
92	96378	96426	96473	96520	96567	96614	96661	96708	96754	96801
93	96848	96895	96941	96988	97034	97081	97127	97174	97220	97266
94	97312	97359	97405	97451	97497	97543	97589	97635	97680	97726
95	97772	97818	97863	97909	97954	98000	98045	98091	98136	98181
96	98227	98272	98317	98362	98407	98452	98497	98542	98587	98632
97	98677	98721	98766	98811	98855	98900	98945	98989	99033	99078
98	99122	99166	99211	99255	99299	99343	99387	99431	99475	99519
99	99563	99607	99651	99694	99738	99782	99825	99869	99913	99956

TRIGONOMETRIC FUNCTIONS OF ACUTE ANGLES

In any right-angled triangle AMP (Fig. 1), M being the right angle, with reference to the angle A let MP be denoted as the opposite side, and AM the adjacent side. AP is the hypotenuse.

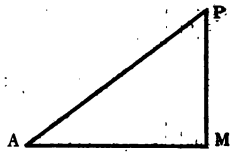


Fig. 1

Then

$$\sin A = \frac{\text{Opposite side}}{\text{Hypotenuse}} = \frac{MP}{AP} = \frac{1}{\operatorname{cosec} A}$$

$$\cos A = \frac{\text{Adjacent side}}{\text{Hypotenuse}} = \frac{AM}{AP} = \frac{1}{\sec A}$$

$$\tan A = \frac{\text{Opposite side}}{\text{Adjacent side}} = \frac{MP}{AM} = \frac{\sin A}{\cos A} = \frac{1}{\cot A}$$

$$\cot A = \frac{\text{Adjacent side}}{\text{Opposite side}} = \frac{AM}{MP} = \frac{\cos A}{\sin A} = \frac{1}{\tan A}$$

$$\sec A = \frac{\text{Hypotenuse}}{\text{Adjacent side}} = \frac{AP}{AM} = \frac{1}{\cos A}$$

$$\operatorname{cosec} A = \frac{\text{Hypotenuse}}{\text{Opposite side}} = \frac{AP}{MP} = \frac{1}{\sin A}$$

Also

$\sin A \operatorname{cosec} A = 1$	$\sin^2 A + \cos^2 A = 1$
$\cos A \sec A = 1$	$\tan^2 A + 1 = \sec^2 A$
$\tan A \cot A = 1$	$1 + \cot^2 A = \operatorname{cosec}^2 A$

NATURAL SINES, COSECANTS, TANGENTS, ETC.

°	′	Sine	Cosecant	Tangent	Cotangent	Secant	Cosine	′	°
0	0	.000000	Infinite	.000000	Infinite	1.00000	1.000000	0	90
	10	.002909	343.77516	.002909	343.77371	1.00000	.999996	50	
	20	.005818	171.88831	.005818	171.88540	1.00002	.999983	40	
	30	.008727	114.59301	.008727	114.58865	1.00004	.999962	30	
	40	.011635	85.945609	.011636	85.939791	1.00007	.999932	20	
	50	.014544	68.757360	.014545	68.750087	1.00011	.999894	10	
1	0	.017452	57.298688	.017455	57.289962	1.00015	.999848	0	89
	10	.020361	49.114062	.020365	49.103881	1.00021	.999793	50	
	20	.023269	42.975713	.023275	42.964077	1.00027	.999729	40	
	30	.026177	38.201550	.026186	38.188459	1.00034	.999657	30	
	40	.029085	34.382316	.029097	34.367771	1.00042	.999577	20	
	50	.031992	31.257577	.032009	31.241577	1.00051	.999488	10	
2	0	.034899	28.653708	.034921	28.636253	1.00061	.999391	0	88
	10	.037806	26.450510	.037834	26.431600	1.00072	.999285	50	
	20	.040713	24.562123	.040747	24.541758	1.00083	.999171	40	
	30	.043619	22.925586	.043661	22.903766	1.00095	.999048	30	
	40	.046525	21.493676	.046576	21.470401	1.00108	.998917	20	
	50	.049431	20.230284	.049491	20.205553	1.00122	.998778	10	
3	0	.052336	19.107323	.052408	19.081137	1.00137	.998630	0	87
	10	.055241	18.102619	.055325	18.074977	1.00153	.998473	50	
	20	.058145	17.198434	.058243	17.169337	1.00169	.998308	40	
	30	.061049	16.380408	.061163	16.349855	1.00187	.998135	30	
	40	.063952	15.636793	.064083	15.604784	1.00205	.997357	20	
	50	.066854	14.957882	.067004	14.924417	1.00224	.997763	10	
4	0	.069756	14.335587	.069927	14.300666	1.00244	.997564	0	86
	10	.072658	13.763115	.072851	13.726738	1.00265	.997357	50	
	20	.075559	13.234717	.075776	13.196888	1.00287	.997141	40	
	30	.078459	12.745495	.078702	12.706205	1.00309	.996917	30	
	40	.081359	12.291252	081629	12.250505	1.00333	.996685	20	
	50	.084258	11.868370	084558	11.826167	1.00357	.996444	10	
5	0	.087156	11.473713	.087489	11.430052	1.00382	.996195	0	85
	10	.090053	11.104549	.090421	11.059431	1.00408	.995937	50	
	20	.092950	10.758488	.093354	10.711913	1.00435	.995671	40	
	30	.095846	10.433431	.096289	10.385397	1.00463	.995396	30	
	40	.098741	10.127522	.099226	10.078031	1.00491	.995113	20	
	50	.101635	9.8391227	.102164	9.7881732	1.00521	.994822	10	
6	0	.104528	9.5667722	.105104	9.5143645	1.00551	.994522	0	84
	10	.107421	9.3091699	.108046	9.2553035	1.00582	.994214	50	
	20	.110313	9.0651512	.110990	9.0098261	1.00614	.993897	40	
	30	.113203	8.8336715	.113936	8.7768874	1.00647	.993572	30	
	40	.116093	8.6137901	.116883	8.5555468	1.00681	.993238	20	
	50	.118982	8.4045586	.119833	8.3449558	1.00715	.992896	10	83
°	′	Cosine	Secant	Cotangent	Tangent	Cosecant	Sine	′	°

For functions from 83°-10′ to 90°-0′ read from bottom of table upward.

NATURAL SINES, COSECANTS, TANGENTS, ETC.
(Continued)

°	′	Sine	Cosecant	Tangent	Cotangent	Secant	Cosine	′	°
7	0	.121869	8.2055090	.122785	8.1443464	1.00751	.992546	0	83
	10	.124756	8.0156450	.125738	7.9530224	1.00787	.992187	50	
	20	.127642	7.8344335	.128694	7.7703506	1.00825	.991820	40	
	30	.130526	7.6612976	.131653	7.5957541	1.00863	.991445	30	
	40	.133410	7.4957100	.134613	7.4287064	1.00902	.991061	20	
	50	.136292	7.3371909	.137576	7.2687255	1.00942	.990669	10	
8	0	.139173	7.1852965	.140541	7.1153697	1.00983	.990268	0	82
	10	.142053	7.0396220	.143508	6.9682335	1.01024	.989859	50	
	20	.144932	6.8997942	.146478	6.8269437	1.01067	.989442	40	
	30	.147809	6.7654691	.149451	6.6911562	1.01111	.989016	30	
	40	.150686	6.6363293	.152426	6.5605538	1.01155	.988582	20	
	50	.153561	6.5120812	.155404	6.4348428	1.01200	.988139	10	
9	0	.156434	6.3924532	.158384	6.3137515	1.01247	.987688	0	81
	10	.159307	6.2771933	.161368	6.1970279	1.01294	.987229	50	
	20	.162178	6.1660674	.164354	6.0844381	1.01342	.986762	40	
	30	.165048	6.0588980	.167343	5.9757644	1.01391	.986286	30	
	40	.167916	5.9553625	.170334	5.8708042	1.01440	.985801	20	
	50	.170783	5.8553921	.173329	5.7693688	1.01491	.985309	10	
10	0	.173648	5.7587705	.176327	5.6712818	1.01543	.984808	0	80
	10	.176512	5.6653331	.179328	5.5763786	1.01595	.984298	50	
	20	.179375	5.5749258	.182332	5.4845052	1.01649	.983781	40	
	30	.182236	5.4874043	.185339	5.3955172	1.01703	.983255	30	
	40	.185095	5.4026333	.188359	5.3092793	1.01758	.982721	20	
	50	.187953	5.3204860	.191363	5.2256647	1.01815	.982178	10	
11	0	.190809	5.2408431	.194380	5.1445540	1.01872	.981627	0	79
	10	.193664	5.1635924	.197401	5.0658352	1.01930	.981068	50	
	20	.196517	5.0886284	.200425	4.9894027	1.01989	.980500	40	
	30	.199368	5.0158317	.203452	4.9151570	1.02049	.979925	30	
	40	.202218	4.9451687	.206483	4.8430045	1.02110	.979341	20	
	50	.205065	4.8764907	.209518	4.7728568	1.02171	.978748	10	
12	0	.207912	4.8097343	.212557	4.7046301	1.02234	.978148	0	78
	10	.210756	4.7448206	.215599	4.6382457	1.02298	.977539	50	
	20	.213599	4.6816748	.218645	4.5736287	1.02362	.976921	40	
	30	.216440	4.6202263	.221695	4.5107085	1.02428	.976296	30	
	40	.219279	4.5604080	.224748	4.4494181	1.02494	.975662	20	
	50	.222116	4.5021565	.227806	4.3896940	1.02562	.975020	10	
13	0	.224951	4.4454115	.230868	4.3314759	1.02630	.974370	0	77
	10	.227784	4.3901158	.233934	4.2747066	1.02700	.973712	50	
	20	.230616	4.3362150	.237004	4.2193318	1.02770	.973045	40	
	30	.233445	4.2836576	.240079	4.1652998	1.02842	.972370	30	
	40	.236273	4.2323943	.243158	4.1125614	1.02914	.971687	20	
	50	.239098	4.1823785	.246241	4.0610700	1.02987	.970995	10	76
°	′	Cosine	Secant	Cotangent	Tangent	Cosecant	Sine	′	°

For functions from 76°-10′ to 83°-0′ read from bottom of table upward.

NATURAL SINES, COSECANTS, TANGENTS, ETC. (Continued)

°	′	Sine	Cosecant	Tangent	Cotangent	Secant	Cosine	′	°
14	0	.241922	4.1335655	.249328	4.0107809	1.03061	.970296	0	76
	10	.244743	4.0859130	.252420	3.9616518	1.03137	.969588	50	
	20	.247563	4.0393804	.255517	3.9136420	1.03213	.968872	40	
	30	.250380	3.9939292	.258618	3.8667131	1.03290	.968148	30	
	40	.253195	3.9495224	.261723	3.8208281	1.03363	.967415	20	
	50	.256008	3.9061250	.264834	3.7759519	1.03447	.966675	10	
15	0	.258819	3.8637033	.267949	3.7320508	1.03528	.965926	0	75
	10	.261628	3.8222251	.271069	3.6890927	1.03609	.965169	50	
	20	.264434	3.7816596	.274195	3.6470467	1.03691	.964404	40	
	30	.267238	3.7419775	.277325	3.6058835	1.03774	.963630	30	
	40	.270040	3.7031506	.280460	3.5655749	1.03858	.962849	20	
	50	.272840	3.6651518	.283600	3.5260938	1.03944	.962059	10	
16	0	.275637	3.6279553	.286745	3.4874144	1.04030	.961262	0	74
	10	.278432	3.5915363	.289896	3.4495120	1.04117	.960456	50	
	20	.281225	3.5558710	.293052	3.4123626	1.04206	.959642	40	
	30	.284015	3.5209365	.296214	3.3759434	1.04295	.958820	30	
	40	.286803	3.4867110	.299380	3.3402326	1.04385	.957990	20	
	50	.289589	3.4531735	.302553	3.3052091	1.04477	.957151	10	
17	0	.292372	3.4203036	.305731	3.2708526	1.04569	.956305	0	73
	10	.295152	3.3880820	.308914	3.2371438	1.04663	.955450	50	
	20	.297930	3.3564900	.312104	3.2040638	1.04757	.954588	40	
	30	.300706	3.3255095	.315299	3.1715948	1.04853	.953717	30	
	40	.303479	3.2951234	.318500	3.1397194	1.04950	.952838	20	
	50	.306249	3.2653149	.321707	3.1084210	1.05047	.951951	10	
18	0	.309017	3.2360680	.324920	3.0776835	1.05146	.951057	0	72
	10	.311782	3.2073673	.328139	3.0474915	1.05246	.950154	50	
	20	.314545	3.1791978	.331364	3.0178301	1.05347	.949243	40	
	30	.317305	3.1515453	.334595	2.9886850	1.05449	.948324	30	
	40	.320062	3.1243959	.337833	2.9600422	1.05552	.947397	20	
	50	.322816	3.0977363	.341077	2.9318885	1.05657	.946462	10	
19	0	.325568	3.0715535	.344328	2.9042109	1.05762	.945519	0	71
	10	.328317	3.0458352	.347585	2.8769970	1.05869	.944568	50	
	20	.331063	3.0205693	.350848	2.8502349	1.05976	.943609	40	
	30	.333807	2.9957443	.354119	2.8239129	1.06085	.942641	30	
	40	.336547	2.9713490	.357396	2.7980198	1.06195	.941666	20	
	50	.339285	2.9473724	.360680	2.7725448	1.06306	.940684	10	
20	0	.342020	2.9238044	.363970	2.7474774	1.06418	.939693	0	70
	10	.344752	2.9006346	.367268	2.7228076	1.06531	.938694	50	
	20	.347481	2.8778532	.370573	2.6985254	1.06645	.937687	40	
	30	.350207	2.8554510	.373885	2.6746215	1.06761	.936672	30	
	40	.352931	2.8334185	.377204	2.6510867	1.06878	.935650	20	
	50	.355651	2.8117471	.380530	2.6279121	1.06995	.934619	10	69
°	′	Cosine	Secant	Cotangent	Tangent	Cosecant	Sine	′	°

For functions from 69°-10′ to 76°-0′′ read from bottom of table upward.

NATURAL SINES, COSECANTS, TANGENTS, ETC.
(Continued)

°	'	Sine	Cosecant	Tangent	Cotangent	Secant	Cosine	'	°
21	0	.358368	2.7904281	.383864	2.6050891	1.07115	.933580	0	69
	10	.361082	2.7694532	.387205	2.5826094	1.07235	.932534	50	
	20	.363793	2.7488144	.390554	2.5604649	1.07356	.931480	40	
	30	.366501	2.7285038	.393911	2.5386479	1.07479	.930418	30	
	40	.369206	2.7085139	.397275	2.5171507	1.07602	.929348	20	
	50	.371908	2.6888374	.400647	2.4959661	1.07727	.928270	10	
22	0	.374607	2.6694672	.404026	2.4750869	1.07853	.927184	0	68
	10	.377302	2.6503962	.407414	2.4545061	1.07981	.926090	50	
	20	.379994	2.6316180	.410810	2.4342172	1.08109	.924989	40	
	30	.382683	2.6131259	.414214	2.4142136	1.08239	.923880	30	
	40	.385369	2.5949137	.417626	2.3944889	1.08370	.922762	20	
	50	.388052	2.5769753	.421046	2.3750372	1.08503	.921638	10	
23	0	.390731	2.5593047	.424475	2.3558524	1.08636	.920505	0	67
	10	.393407	2.5418961	.427912	2.3369287	1.08771	.919364	50	
	20	.396080	2.5247440	.431358	2.3182606	1.08907	.918216	40	
	30	.398749	2.5078428	.434812	2.2998425	1.09044	.917060	30	
	40	.401415	2.4911874	.438276	2.2816693	1.09183	.915896	20	
	50	.404078	2.4747726	.441748	2.2637357	1.09323	.914725	10	
24	0	.406737	2.4585933	.44522[illegible]	2.2460368	1.09464	.913545	0	66
	10	.409392	2.4426448	.44871[illegible]	2.2285676	1.09606	.912358	50	
	20	.412045	2.4269222	.452218	2.2113234	1.097[illegible]	.911164	40	
	30	.414693	2.41142[illegible]	.455726	2.1942[illegible]	1.0[illegible]	.909961	30	
	40	.417338	2.3961367	.459244	2.17749[illegible]	1.1[illegible]	[illegible]	20	
	50	.419980	2.3810650	.462771	2.16[illegible]	1.1[illegible]	[illegible]	10	
25	0	.422618	2.3662016	.466[illegible]	2.1445069	1.103[illegible]	[illegible]	[illegible]	65
	10	.425253	2.3515424	.469854	2.1283213	1.10488	[illegible]	[illegible]	
	20	.427884	2.337[illegible]533	.4734[illegible]	2.1123348	1.1064[illegible]	[illegible]	[illegible]	
	30	.430511	2.3228[illegible]	.476976	2.[illegible]5436	1.1[illegible]	[illegible]	[illegible]	
	40	.433135	2.30[illegible]	.48[illegible]	2.[illegible]9435	1.1[illegible]947	[illegible]	[illegible]	
	50	.435755	2.2948685	.48413[illegible]	2.[illegible]5531[illegible]	1.11[illegible]	[illegible]	[illegible]	
26	0	.43837[illegible]	2.2811[illegible]	.4877[illegible]	2.[illegible]	1.1126[illegible]	.8987[illegible]	[illegible]	64
	10	.440984	2.2676[illegible]	.491[illegible]	2.[illegible]	1.1142[illegible]	[illegible]	[illegible]	
	20	.443593	2.2543[illegible]	.494[illegible]	[illegible]	1.1157[illegible]	[illegible]	[illegible]	
	30	.4461[illegible]	2.241[illegible]	[illegible]	[illegible]	1.1174[illegible]	[illegible]	[illegible]	
	40	.4487[illegible]	2.228[illegible]	.5022[illegible]	1.[illegible]	[illegible]	[illegible]	[illegible]	
	50	.4513[illegible]	2.2153[illegible]	[illegible]	1.97[illegible]	[illegible]	[illegible]	[illegible]	
27	0	.4539[illegible]	2.2[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	10	.4565[illegible]	2.1[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
	20	.45916[illegible]	2.1[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
	30	.4617[illegible]	2.1[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
	40	.4643[illegible]	2.1[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
	50	.4669[illegible]	2.1417[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
°	'	Cosine	Secant	Cotangent	Tangent	Cosecant	Sine	'	°

For functions from [illegible] to 69° 0' read from bottom of table upward.

NATURAL SINES, COSECANTS, TANGENTS, ETC.
(Continued)

°	′	Sine	Cosecant	Tangent	Cotangent	Secant	Cosine	′	°
28	0	.469472	2.1300545	.531709	1.8807265	1.13257	.882948	0	62
	10	.472038	2.1184737	.535547	1.8676003	1.13433	.881578	50	
	20	.474600	2.1070359	.539195	1.8546159	1.13610	.880201	40	
	30	.477159	2.0957385	.542956	1.8417409	1.13789	.878817	30	
	40	.479713	2.0845792	.546728	1.8290628	1.13970	.877425	20	
	50	.482263	2.0735556	.550515	1.8164892	1.14152	.876026	10	
29	0	.484810	2.0626653	.554309	1.8040478	1.14335	.874620	0	61
	10	.487352	2.0519061	.558118	1.7917362	1.14521	.873206	50	
	20	.489890	2.0412757	.561939	1.7795524	1.14707	.871784	40	
	30	.492424	2.0307720	.565773	1.7674940	1.14896	.870356	30	
	40	.494953	2.0203929	.569619	1.7555590	1.15085	.868920	20	
	50	.497479	2.0101362	.573478	1.7437453	1.15277	.867476	10	
30	0	.500000	2.0000000	.577350	1.7320508	1.15470	.866025	0	60
	10	.502517	1.9899822	.581235	1.7204736	1.15665	.864567	50	
	20	.505030	1.9800810	.585134	1.7090116	1.15861	.863102	40	
	30	.507538	1.9702944	.589045	1.6976631	1.16059	.861629	30	
	40	.510043	1.9606206	.592970	1.6864261	1.16259	.860149	20	
	50	.512543	1.9510577	.596908	1.6752988	1.16460	.858662	10	
31	0	.515038	1.9416040	.600861	1.6642795	1.16663	.857167	0	59
	10	.517529	1.9322578	.604827	1.6533663	1.16868	.855665	50	
	20	.520016	1.9230173	.608807	1.6425576	1.17075	.854156	40	
	30	.522499	1.9138809	.612801	1.6318517	1.17283	.852640	30	
	40	.524977	1.9048469	.616809	1.6212469	1.17493	.851117	20	
	50	.527450	1.8959138	.620832	1.6107417	1.17704	.849586	10	
32	0	.529919	1.8870799	.624869	1.6003345	1.17918	.848048	0	58
	10	.532384	1.8783438	.628921	1.5900238	1.18133	.846503	50	
	20	.534844	1.8697040	.632988	1.5798079	1.18350	.844951	40	
	30	.537300	1.8611590	.637079	1.5696856	1.18569	.843391	30	
	40	.539751	1.8527073	.641167	1.5596552	1.18790	.841825	20	
	50	.542197	1.8443476	.645280	1.5497155	1.19012	.840251	10	
33	0	.544639	1.8360785	.649408	1.5398650	1.19236	.838671	0	57
	10	.547076	1.8278985	.653531	1.5301025	1.19463	.837083	50	
	20	.549509	1.8198065	.657710	1.5204261	1.19691	.835488	40	
	30	.551937	1.8118010	.661886	1.5108352	1.19920	.833886	30	
	40	.554360	1.8038809	.666077	1.5013282	1.20152	.832277	20	
	50	.556779	1.7960449	.670285	1.4919039	1.20386	.830661	10	
34	0	.559193	1.7882916	.674509	1.4825610	1.20622	.829038	0	56
	10	.561602	1.7806201	.678749	1.4732983	1.20859	.827407	50	
	20	.564007	1.7730290	.683007	1.4641147	1.21099	.825770	40	
	30	.566406	1.7655173	.687281	1.4550090	1.21341	.824126	30	
	40	.568801	1.7580837	.691573	1.4459801	1.21584	.822475	20	
	50	.571191	1.7507273	.695881	1.4370268	1.21830	.820817	10	55
°	′	Cosine	Secant	Cotangent	Tangent	Cosecant	Sine	′	°

For functions from 55°-10′ to 62°-0′ read from bottom of table upward.

NATURAL SINES, COSECANTS, TANGENTS, ETC.
(Continued)

°	′	Sine	Cosecant	Tangent	Cotangent	Secant	Cosine	′	°
35	0	.573576	1.7434468	.700208	1.4281480	1.22077	.819152	0	55
	10	.575957	1.7362413	.704552	1.4193427	1.22327	.817480	50	
	20	.578332	1.7291096	.708913	1.4106098	1.22579	.815801	40	
	30	.580703	1.7220508	.713293	1.4019483	1.22833	.814116	30	
	40	.583069	1.7150639	.717691	1.3933571	1.23089	.812423	20	
	50	.585429	1.7081478	.722108	1.3848355	1.23347	.810723	10	
36	0	.587785	1.7013016	.726543	1.3763810	1.23607	.809017	0	54
	10	.590136	1.6945244	.730996	1.3679959	1.23869	.807304	50	
	20	.592482	1.6878151	.735469	1.3596764	1.24134	.805584	40	
	30	.594823	1.6811730	.739961	1.3514224	1.24400	.803857	30	
	40	.597159	1.6745970	.744472	1.3432331	1.24669	.802123	20	
	50	.599489	1.6680864	.749003	1.3351075	1.24940	.800383	10	
37	0	.601815	1.6616401	.753554	1.3270448	1.25214	.798636	0	53
	10	.604136	1.6552575	.758125	1.3190441	1.25489	.796882	50	
	20	.606451	1.6489376	.762716	1.3111046	1.25767	.795121	40	
	30	.608761	1.6426796	.767627	1.3032254	1.26047	.793353	30	
	40	.611067	1.6364828	.771959	1.2954057	1.26330	.791579	20	
	50	.613367	1.6303462	.776612	1.2876447	1.26615	.789798	10	
38	0	.615661	1.6242692	.781286	1.2799416	1.26902	.788011	0	52
	10	.617951	1.6182510	.785981	1.2722957	1.27191	.786217	50	
	20	.620235	1.6122908	.790698	1.2647062	1.27483	.784416	40	
	30	.622515	1.6063879	.795436	1.2571723	1.27778	.782608	30	
	40	.624789	1.6005416	.800196	1.2496933	1.28075	.780794	20	
	50	.627057	1.5947511	.804080	1.2422685	1.28374	.778973	10	
39	0	.629320	1.5890157	.809784	1.2348972	1.28676	.777146	0	51
	10	.631578	1.5833318	.814612	1.2275786	1.28980	.775312	50	
	20	.633831	1.5777077	.819463	1.2203121	1.29287	.773472	40	
	30	.636078	1.5721337	.824336	1.2130970	1.29597	.771625	30	
	40	.638320	1.5666121	.829234	1.2059327	1.29909	.769771	20	
	50	.640557	1.5611424	.834155	1.1988184	1.30223	.767911	10	
40	0	.642788	1.5557238	.839100	1.1917536	1.30541	.766044	0	50
	10	.645013	1.5503558	.844069	1.1847376	1.30861	.764171	50	
	20	.647233	1.5450378	.849062	1.1777698	1.31183	.762292	40	
	30	.649448	1.5397690	.854081	1.1708496	1.31509	.760406	30	
	40	.651657	1.5345491	.859124	1.1639763	1.31837	.758514	20	
	50	.653861	1.5293773	.864193	1.1571495	1.32168	.756615	10	
41	0	.656059	1.5242531	.869287	1.1503684	1.32501	.754710	0	49
	10	.658252	1.5191759	.874407	1.1436326	1.32838	.752798	50	
	20	.660439	1.5141452	.879553	1.1369414	1.33177	.750880	40	
	30	.662620	1.5091605	.884725	1.1302944	1.33519	.748956	30	
	40	.664796	1.5042211	.889924	1.1236909	1.33864	.747025	20	
	50	.666966	1.4993267	.895151	1.1171305	1.34212	.745088	10	48
°	′	Cosine	Secant	Cotangent	Tangent	Cosecant	Sine	′	°

For functions from 48°-10′ to 55°-0′ read from bottom of table upward.

NATURAL SINES, COSECANTS, TANGENTS, ETC.

(Continued)

°	′	Sine	Cosecant	Tangent	Cotangent	Secant	Cosine	′	°
42	0	.669131	1.4944765	.900404	1.1106125	1.34563	.743145	0	48
	10	.671289	1.4896703	.905685	1.1041365	1.34917	.741195	50	
	20	.673443	1.4849073	.910994	1.0977020	1.35274	.739239	40	
	30	.675590	1.4801872	.916331	1.0913085	1.35634	.737277	30	
	40	.677732	1.4755095	.921697	1.0849554	1.35997	.735309	20	
	50	.679868	1.4708736	.927091	1.0786423	1.36363	.733335	10	
43	0	.681998	1.4662792	.932515	1.0723687	1.36733	.731354	0	47
	10	.684123	1.4617257	.937968	1.0661341	1.37105	.729367	50	
	20	.686242	1.4572127	.943451	1.0599381	1.37481	.727374	40	
	30	.688355	1.4527397	.948965	1.0537801	1.37860	.725374	30	
	40	.690462	1.4483063	.954508	1.0476598	1.38242	.723369	20	
	50	.692563	1.4439120	.960083	1.0415767	1.38628	.721357	10	
44	0	.694658	1.4395565	.965689	1.0355303	1.39016	.719340	0	46
	10	.696748	1.4352393	.971326	1.0295203	1.39409	.717316	50	
	20	.698832	1.4309602	.976996	1.0235461	1.39804	.715286	40	
	30	.700909	1.4267182	.982697	1.0176074	1.40203	.713251	30	
	40	.702981	1.4225134	.988432	1.0117088	1.40606	.711209	20	
	50	.705047	1.4183454	.994199	1.0058348	1.41012	.709161	10	
45	0	.707107	1.4142136	1.00000	1.0000000	1.41421	.707107	0	45
°	′	Cosine	Secant	Cotangent	Tangent	Cosecant	Sine	′	°

For functions from 45° 0′ to 48°-0′ read from bottom of table upward.

SQUARES, CUBES, SQUARE ROOTS, CUBE ROOTS AND RECIPROCALS

No.	Squares	Cubes	Square roots	Cube roots	Reciprocals
1	1	1	1.0000000	1.0000000	1.000000000
2	4	8	1.4142136	1.2599210	.500000000
3	9	27	1.7320508	1.4422496	.333333333
4	16	64	2.0000000	1.5874011	.250000000
5	25	125	2.2360680	1.7099759	.200000000
6	36	216	2.4494897	1.8171206	.166666667
7	49	343	2.6457513	1.9129312	.142857143
8	64	512	2.8284271	2.0000000	.125000000
9	81	729	3.0000000	2.0800837	.111111111
10	100	1000	3.1622777	2.1544347	.100000000
11	121	1331	3.3166248	2.2239801	.090909091
12	144	1728	3.4641016	2.2894286	.083333333
13	169	2197	3.6055513	2.3513347	.076923077
14	196	2744	3.7416574	2.4101422	.071428571
15	225	3375	3.8729833	2.4662121	.066666667
16	256	4096	4.0000000	2.5198421	.062500000
17	289	4913	4.1231056	2.5712816	.058823529
18	324	5832	4.2426407	2.6207414	.055555556
19	361	6859	4.3588989	2.6684016	.052631579
20	400	8000	4.4721360	2.7144177	.050000000
21	441	9261	4.5825757	2.7589243	.047619048
22	484	10648	4.6904158	2.8020393	.045454545
23	529	12167	4.7958315	2.8438670	.043478261
24	576	13824	4.8989795	2.8844991	.041666667
25	625	15625	5.0000000	2.9240177	.040000000
26	676	17576	5.0990195	2.9624960	.038461538
27	729	19683	5.1961524	3.0000000	.037037037
28	784	21952	5.2915026	3.0365889	.035714286
29	841	24389	5.3851648	3.0723168	.034482759
30	900	27000	5.4772256	3.1072325	.033333333
31	961	29791	5.5677644	3.1413806	.032258065
32	1024	32768	5.6568542	3.1748021	.031250000
33	1089	35937	5.7445626	3.2075343	.030303030
34	1156	39304	5.8309519	3.2396118	.029411765
35	1225	42875	5.9160798	3.2710663	.028571429
36	1296	46656	6.0000000	3.3019272	.027777778
37	1369	50653	6.0827625	3.3322218	.027027027
38	1444	54872	6.1644140	3.3619754	.026315789
39	1521	59319	6.2449980	3.3912114	.025641026
40	1600	64000	6.3245553	3.4199519	.025000000
41	1681	68921	6.4031242	3.4482172	.024390244
42	1764	74088	6.4807407	3.4760266	.023809524
43	1849	79507	6.5574385	3.5033981	.023255814
44	1936	85184	6.6332496	3.5303483	.022727273
45	2025	91125	6.7082039	3.5568933	.022222222
46	2116	97336	6.7823300	3.5830479	.021739130
47	2209	103823	6.8556546	3.6088261	.021276600
48	2304	110592	6.9282032	3.6342411	.020833333
49	2401	117649	7.0000000	3.6593057	.020408163
50	2500	125000	7.0710678	3.6840314	.020000000
51	2601	132651	7.1414284	3.7084298	.019607843
52	2704	140608	7.2111026	3.7325111	.019230769

SQUARES, CUBES, SQUARE ROOTS, CUBE ROOTS AND RECIPROCALS—(Continued)

No.	Squares	Cubes	Square roots	Cube roots	Reciprocals
53	2809	148877	7.2801099	3.7562858	.018867925
54	2916	157464	7.3484692	3.7797631	.018518519
55	3025	166375	7.4161985	3.8029525	.018181818
56	3136	175616	7.4833148	3.8258624	.017857143
57	3249	185193	7.5498344	3.8485011	.017543860
58	3364	195112	7.6157731	3.8708766	.017241379
59	3481	205379	7.6811457	3.8929965	.016949153
60	3600	216000	7.7459667	3.9148676	.016666667
61	3721	226981	7.8102497	3.9364972	.016393443
62	3844	238328	7.8740079	3.9578915	.016129032
63	3969	250047	7.9372539	3.9790571	.015873016
64	4096	262144	8.0000000	4.0000000	.015625000
65	4225	274625	8.0622577	4.0207256	.015384615
66	4356	287496	8.1240384	4.0412401	.015151515
67	4489	300763	8.1853528	4.0615480	.014925373
68	4624	314432	8.2462113	4.0816551	.014705882
69	4761	328509	8.3066239	4.1015661	.014492754
70	4900	343000	8.3666003	4.1212853	.014285714
71	5041	357911	8.4261498	4.1408178	.014084507
72	5184	373248	8.4852814	4.1601676	.013888889
73	5329	389017	8.5440037	4.1793390	.013698630
74	5476	405224	8.6023253	4.1983364	.013513514
75	5625	421875	8.6602540	4.2171633	.013333333
76	5776	438976	8.7177979	4.2358236	.013157895
77	5929	456533	8.7749644	4.2543210	.012987013
78	6084	474552	8.8317609	4.2726586	.012820513
79	6241	493039	8.8881944	4.2908404	.012658228
80	6400	512000	8.9442719	4.3088695	.012500000
81	6561	531441	9.0000000	4.3267487	.012345679
82	6724	551368	9.0553851	4.3444815	.012195122
83	6889	571787	9.1104336	4.3620707	.012048193
84	7056	592704	9.1651514	4.3795191	.011904762
85	7225	614125	9.2195445	4.3968296	.011764706
86	7396	636056	9.2736185	4.4140049	.011627907
87	7569	658503	9.3273791	4.4310476	.011494253
88	7744	681472	9.3808315	4.4479602	.011363636
89	7921	704969	9.4339811	4.4647451	.011235955
90	8100	729000	9.4868330	4.4814047	.011111111
91	8281	753571	9.5393920	4.4979414	.010989011
92	8464	778688	9.5916630	4.5143574	.010869565
93	8649	804357	9.6436508	4.5306549	.010752688
94	8836	830584	9.6953597	4.5468359	.010638298
95	9025	857375	9.7467943	4.5629026	.010526316
96	9216	884736	9.7979590	4.5788570	.010416667
97	9409	912673	9.8488578	4.5947009	.010309278
98	9604	941192	9.8994949	4.6104363	.010204082
99	9801	970299	9.9498744	4.6260650	.010101010
100	10000	1000000	10.0000000	4.6415888	.010000000
101	10201	1030301	10.0498756	4.6570095	.009900990
102	10404	1061208	10.0995049	4.6723287	.009803922
103	10609	1092727	10.1488916	4.6875482	.009708738

SQUARES, CUBES, SQUARE ROOTS, CUBE ROOTS AND RECIPROCALS—(Continued)

No.	Squares	Cubes	Square roots	Cube roots	Reciprocals
104	10816	1124864	10.1980390	4.7026694	.009615385
105	11025	1157625	10.2469508	4.7176940	.009523810
106	11236	1191016	10.2956301	4.7326235	.009433962
107	11449	1225043	10.3440804	4.7474594	.009345794
108	11664	1259712	10.3923048	4.7622032	.009259259
109	11881	1295029	10.4403065	4.7768562	.009174312
110	12100	1331000	10.4880885	4.7914199	.009090909
111	12321	1367631	10.5356538	4.8058955	.009009009
112	12544	1404928	10.5830052	4.8202845	.008928571
113	12769	1442897	10.6301458	4.8345881	.008849558
114	12996	1481544	10.6770783	4.8488076	.008771930
115	13225	1520875	10.7238053	4.8629442	.008695652
116	13456	1560896	10.7703296	4.8769990	.008620690
117	13689	1601613	10.8166538	4.8909732	.008547009
118	13924	1643032	10.8627805	4.9048681	.008474576
119	14161	1685159	10.9087121	4.9186847	.008403361
120	14400	1728000	10.9544512	4.9324242	.008333333
121	14641	1771561	11.0000000	4.9460874	.008264463
122	14884	1815848	11.0453610	4.9596757	.008196721
123	15129	1860867	11.0905365	4.9731898	.008130081
124	15376	1906624	11.1355287	4.9866310	.008064516
125	15625	1953125	11.1803399	5.0000000	.008000000
126	15876	2000376	11.2249722	5.0132979	.007936508
127	16129	2048383	11.2694277	5.0265257	.007874016
128	16384	2097152	11.3137085	5.0396842	.007812500
129	16641	2146689	11.3578167	5.0527743	.007751938
130	16900	2197000	11.4017543	5.0657970	.007692308
131	17161	2248091	11.4455231	5.0787531	.007633588
132	17424	2299968	11.4891253	5.0916434	.007575758
133	17689	2352637	11.5325626	5.1044687	.007518797
134	17956	2406104	11.5758369	5.1172299	.007462687
135	18225	2460375	11.6189500	5.1299278	.007407407
136	18496	2515456	11.6619038	5.1425632	.007352941
137	18769	2571353	11.7046999	5.1551367	.007299270
138	19044	2628072	11.7473401	5.1676493	.007246377
139	19321	2685619	11.7898261	5.1801015	.007194245
140	19600	2744000	11.8321596	5.1924941	.007142857
141	19881	2803221	11.8743421	5.2048279	.007092199
142	20164	2863288	11.9163753	5.2171034	.007042254
143	20449	2924207	11.9582607	5.2293215	.006993007
144	20736	2985984	12.0000000	5.2414828	.006944444
145	21025	3048625	12.0415946	5.2535879	.006896552
146	21316	3112136	12.0830460	5.2656374	.006849315
147	21609	3176523	12.1243557	5.2776321	.006802721
148	21904	3241792	12.1655251	5.2895725	.006756757
149	22201	3307949	12.2065556	5.3014592	.006711409
150	22500	3375000	12.2474487	5.3132928	.006666667
151	22801	3442951	12.2882057	5.3250740	.006622517
152	23104	3511808	12.3288280	5.3368033	.006578947
153	23409	3581577	12.3693169	5.3484812	.006535948
154	23716	3652264	12.4096736	5.3601084	.006493506

SQUARES, CUBES, SQUARE ROOTS, CUBE ROOTS AND RECIPROCALS—(Continued)

No.	Squares	Cubes	Square roots	Cube roots	Reciprocals
155	24025	3723875	12.4498996	5.3716854	.006451613
156	24336	3796416	12.4899960	5.3832126	.006410256
157	24649	3869893	12.5299641	5.3946907	.006369427
158	24964	3944312	12.5698051	5.4061202	.006329114
159	25281	4019679	12.6095202	5.4175015	.006289308
160	25600	4096000	12.6491106	5.4288352	.006250000
161	25921	4173281	12.6885775	5.4401218	.006211180
162	26244	4251528	12.7279221	5.4513618	.006172840
163	26569	4330747	12.7671453	5.4625556	.006134969
164	26896	4410944	12.8062485	5.4737037	.006097561
165	27225	4492125	12.8452326	5.4848066	.006060606
166	27556	4574296	12.8840987	5.4958647	.006024096
167	27889	4657463	12.9228480	5.5068784	.005988024
168	28224	4741632	12.9614814	5.5178484	.005952381
169	28561	4826809	13.0000000	5.5287748	.005917160
170	28900	4913000	13.0384048	5.5396583	.005882353
171	29241	5000211	13.0766968	5.5504991	.005847953
172	29584	5088448	13.1148770	5.5612978	.005813953
173	29929	5177717	13.1529464	5.5720546	.005780347
174	30276	5268024	13.1909060	5.5827702	.005747126
175	30625	5359375	13.2287566	5.5934447	.005714286
176	30976	5451776	13.2664992	5.6040787	.005681818
177	31329	5545233	13.3041347	5.6146724	.005649718
178	31684	5639752	13.3416641	5.6252263	.005617978
179	32041	5735339	13.3790882	5.6357408	.005586592
180	32400	5832000	13.4164079	5.6462162	.005555556
181	32761	5929741	13.4536240	5.6566528	.005524862
182	33124	6028568	13.4907376	5.6670511	.005494505
183	33489	6128487	13.5277493	5.6774114	.005464481
184	33856	6229504	13.5646600	5.6877340	.005434783
185	34225	6331625	13.6014705	5.6980192	.005405405
186	34596	6434856	13.6381817	5.7082675	.005376344
187	34969	6539203	13.6747943	5.7184791	.005347594
188	35344	6644672	13.7113092	5.7286543	.005319149
189	35721	6751269	13.7477271	5.7387936	.005291005
190	36100	6859000	13.7840488	5.7488971	.005263158
191	36481	6967871	13.8202750	5.7589652	.005235602
192	36864	7077888	13.8564065	5.7689982	.005208333
193	37249	7189057	13.8924440	5.7789966	.005181347
194	37636	7301384	13.9283883	5.7889604	.005154639
195	38025	7414875	13.9642400	5.7988900	.005128205
196	38416	7529536	14.0000000	5.8087857	.005102041
197	38809	7645373	14.0356688	5.8186479	.005076142
198	39204	7762392	14.0712473	5.8284767	.005050505
199	39601	7880599	14.1067360	5.8382725	.005025126
200	40000	8000000	14.1421356	5.8480355	.005000000
201	40401	8120601	14.1774469	5.8577660	.004975124
202	40804	8242408	14.2126704	5.8674643	.004950495
203	41209	8365427	14.2478068	5.8771307	.004926108
204	41616	8489664	14.2828569	5.8867653	.004901961
205	42025	8615125	14.3178211	5.8963685	.004878049

SQUARES, CUBES, SQUARE ROOTS, CUBE ROOTS AND RECIPROCALS—(Continued)

No.	Squares	Cubes	Square roots	Cube roots	Reciprocals
206	42436	8741816	14.3527001	5.9059406	.004854369
207	42849	8869743	14.3874946	5.9154817	.004830918
208	43264	8998912	14.4222051	5.9249921	.004807692
209	43681	9129329	14.4568323	5.9344721	.004784689
210	44100	9261000	14.4913767	5.9439220	.004761905
211	44521	9393931	14.5258390	5.9533418	.004739336
212	44944	9528128	14.5602198	5.9627320	.004716981
213	45369	9663597	14.5945195	5.9720926	.004694836
214	45796	9800344	14.6287388	5.9814240	.004672897
215	46225	9938375	14.6628783	5.9907264	.004651163
216	46656	10077696	14.6969385	6.0000000	.004629630
217	47089	10218313	14.7309199	6.0092450	.004608295
218	47524	10360232	14.7648231	6.0184617	.004587156
219	47961	10503459	14.7986486	6.0276502	.004566210
220	48400	10648000	14.8323970	6.0368107	.004545455
221	48841	10793861	14.8660687	6.0459435	.004524887
222	49284	10941048	14.8996644	6.0550489	.004504505
223	49729	11089567	14.9331845	6.0641270	.004484305
224	50176	11239424	14.9666295	6.0731779	.004464286
225	50625	11390625	15.0000000	6.0822020	.004444444
226	51076	11543176	15.0332964	6.0911994	.004424779
227	51529	11697083	15.0665192	6.1001702	.004405286
228	51984	11852352	15.0996689	6.1091147	.004385965
229	52441	12008989	15.1327460	6.1180332	.004366812
230	52900	12167000	15.1657509	6.1269257	.004347826
231	53361	12326391	15.1986842	6.1357924	.004329004
232	53824	12487168	15.2315462	6.1446337	.004310345
233	54289	12649337	15.2643375	6.1534495	.004291845
234	54756	12812904	15.2970585	6.1622401	.004273504
235	55225	12977875	15.3297097	6.1710058	.004255319
236	55696	13144256	15.3622915	6.1797466	.004237288
237	56169	13312053	15.3948043	6.1884628	.004219409
238	56644	13481272	15.4272486	6.1971544	.004201681
239	57121	13651919	15.4596248	6.2058218	.004184100
240	57600	13824000	15.4919334	6.2144650	.004166667
241	58081	13997521	15.5241747	6.2230843	.004149378
242	58564	14172488	15.5563492	6.2316797	.004132231
243	59049	14348907	15.5884573	6.2402515	.004115226
244	59536	14526784	15.6204994	6.2487998	.004098361
245	60025	14706125	15.6524758	6.2573248	.004081633
246	60516	14886936	15.6843871	6.2658266	.004065041
247	61009	15069223	15.7162336	6.2743054	.004048583
248	61504	15252992	15.7480157	6.2827613	.004032258
249	62001	15438249	15.7797338	6.2911946	.004016064
250	62500	15625000	15.8113883	6.2996053	.004000000
251	63001	15813251	15.8429795	6.3079935	.003984064
252	63504	16003008	15.8745079	6.3163596	.003968254
253	64009	16194277	15.9059737	6.3247035	.003952569
254	64516	16387064	15.9373775	6.3330256	.003937008
255	65025	16581375	15.9687194	6.3413257	.003921569

SQUARES, CUBES, SQUARE ROOTS, CUBE ROOTS AND RECIPROCALS—(Continued)

No.	Squares	Cubes	Square roots	Cube roots	Reciprocals
256	65536	16777216	16.0000000	6.3496042	.003906250
257	66049	16974593	16.0312195	6.3578611	.003891051
258	66564	17173512	16.0623784	6.3660968	.003875969
259	67081	17373979	16.0934769	6.3743111	.003861004
260	67600	17576000	16.1245155	6.3825043	.003846154
261	68121	17779581	16.1554944	6.3906765	.003831418
262	68644	17984728	16.1864141	6.3988279	.003816794
263	69169	18191447	16.2172747	6.4069585	.003802281
264	69696	18399744	16.2480768	6.4150687	.003787879
265	70225	18609625	16.2788206	6.4231583	.003773585
266	70756	18821096	16.3095064	6.4312276	.003759398
267	71289	19034163	16.3401346	6.4392767	.003745318
268	71824	19248832	16.3707055	6.4473057	.003731343
269	72361	19465109	16.4012195	6.4553148	.003717472
270	72900	19683000	16.4316767	6.4633041	.003703704
271	73441	19902511	16.4620776	6.4712736	.003690037
272	73984	20123648	16.4924225	6.4792236	.003676471
273	74529	20346417	16.5227116	6.4871541	.003663004
274	75076	20570824	16.5529454	6.4950653	.003649635
275	75625	20796875	16.5831240	6.5029572	.003636364
276	76176	21024576	16.6132477	6.5108300	.003623188
277	76729	21253933	16.6433170	6.5186839	.003610108
278	77284	21484952	16.6733320	6.5265189	.003597122
279	77841	21717639	16.7032931	6.5343351	.003584229
280	78400	21952000	16.7332005	6.5421326	.003571429
281	78961	22188041	16.7630546	6.5499116	.003558719
282	79524	22425768	16.7928556	6.5576722	.003546099
283	80089	22665187	16.8226038	6.5654144	.003533569
284	80656	22906304	16.8522995	6.5731385	.003521127
285	81225	23149125	16.8819430	6.5808443	.003508772
286	81796	23393656	16.9115345	6.5885323	.003496503
287	82369	23639903	16.9410743	6.5962023	.003484321
288	82944	23887872	16.9705627	6.6038545	.003472222
289	83521	24137569	17.0000000	6.6114890	.003460208
290	84100	24389000	17.0293864	6.6191060	.003448276
291	84681	24642171	17.0587221	6.6267054	.003436426
292	85264	24897088	17.0880075	6.6342874	.003424658
293	85849	25153757	17.1172428	6.6418522	.003412969
294	86436	25412184	17.1464282	6.6493998	.003401361
295	87025	25672375	17.1755640	6.6569302	.003389831
296	87616	25934336	17.2046505	6.6644437	.003378378
297	88209	26198073	17.2336879	6.6719403	.003367003
298	88804	26463592	17.2626765	6.6794200	.003355705
299	89401	26730899	17.2916165	6.6868831	.003344482
300	90000	27000000	17.3205081	6.6943295	.003333333
301	90601	27270901	17.3493516	6.7017593	.003322259
302	91204	27543608	17.3781472	6.7091729	.003311258
303	91809	27818127	17.4068952	6.7165700	.003300330
304	92416	28094464	17.4355958	6.7239508	.003289474
305	93025	28372625	17.4642492	6.7313155	.003278689
306	93636	28652616	17.4928557	6.7386641	.003267974

SQUARES, CUBES, SQUARE ROOTS, CUBE ROOTS AND RECIPROCALS—(Continued)

No.	Squares	Cubes	Square roots	Cube roots	Reciprocals
307	94249	28934443	17.5214155	6.7459967	.003257329
308	94864	29218112	17.5499288	6.7533134	.003246753
309	95481	29503629	17.5783958	6.7606143	.003236246
310	96100	29791000	17.6068169	6.7678995	.003225806
311	96721	30080231	17.6351921	6.7751690	.003215434
312	97344	30371328	17.6635217	6.7824229	.003205128
313	97969	30664297	17.6918060	6.7896613	.003194888
314	98596	30959144	17.7200451	6.7968844	.003184713
315	99225	31255875	17.7482393	6.8040921	.003174603
316	99856	31554496	17.7763888	6.8112847	.003164557
317	100489	31855013	17.8044938	6.8184620	.003154574
318	101124	32157432	17.8325545	6.8256242	.003144654
319	101761	32461759	17.8605711	6.8327714	.003134796
320	102400	32768000	17.8885438	6.8399037	.003125000
321	103041	33076161	17.9164729	6.8470213	.003115265
322	103684	33386248	17.9443584	6.8541240	.003105590
323	104329	33698267	17.9722008	6.8612120	.003095975
324	104976	34012224	18.0000000	6.8682855	.003086420
325	105625	34328125	18.0277564	6.8753443	.003076923
326	106276	34645976	18.0554701	6.8823888	.003067485
327	106929	34965783	18.0831413	6.8894188	.003058104
328	107584	35287552	18.1107703	6.8964345	.003048780
329	108241	35611289	18.1383571	6.9034359	.003039514
330	108900	35937000	18.1659021	6.9104232	.003030303
331	109561	36264691	18.1934054	6.9173964	.003021148
332	110224	36594368	18.2208672	6.9243556	.003012048
333	110889	36926037	18.2482876	6.9313008	.003003003
334	111556	37259704	18.2756669	6.9382321	.002994012
335	112225	37595375	18.3030052	6.9451496	.002985075
336	112896	37933056	18.3303028	6.9520533	.002976190
337	113569	38272753	18.3575598	6.9589434	.002967359
338	114244	38614472	18.3847763	6.9658198	.002958580
339	114921	38958219	18.4119526	6.9726826	.002949853
340	115600	39304000	18.4390889	6.9795321	.002941176
341	116281	39651821	18.4661853	6.9863681	.002932551
342	116964	40001688	18.4932420	6.9931906	.002923977
343	117649	40353607	18.5202592	7.0000000	.002915452
344	118336	40707584	18.5472370	7.0067962	.002906977
345	119025	41063625	18.5741756	7.0135791	.002898551
346	119716	41421736	18.6010752	7.0203490	.002890173
347	120409	41781923	18.6279360	7.0271058	.002881844
348	121104	42144192	18.6547581	7.0338497	.002873563
349	121801	42508549	18.6815417	7.0405806	.002865330
350	122500	42875000	18.7082869	7.0472987	.002857143
351	123201	43243551	18.7349940	7.0540041	.002849003
352	123904	43614208	18.7616630	7.0606967	.002840909
353	124609	43986977	18.7882942	7.0673767	.002832861
354	125316	44361864	18.8148877	7.0740440	.002824859
355	126025	44738875	18.8414437	7.0806988	.002816901
356	126736	45118016	18.8679623	7.0873411	.002808989
357	127449	45499293	18.8944436	7.0939709	.002801120

SQUARES, CUBES, SQUARE ROOTS, CUBE ROOTS AND RECIPROCALS—(Continued)

No.	Squares	Cubes	Square roots	Cube roots	Reciprocals
358	128164	45882712	18.9208879	7.1005885	.002793296
359	128881	46268279	18.9472953	7.1071937	.002785515
360	129600	46656000	18.9736660	7.1137866	.002777778
361	130321	47045881	19.0000000	7.1203674	.002770083
362	131044	47437928	19.0262976	7.1269360	.002762431
363	131769	47832147	19.0525589	7.1334925	.002754821
364	132496	48228544	19.0787840	7.1400370	.002747253
365	133225	48627125	19.1049732	7.1465695	.002739726
366	133956	49027896	19.1311265	7.1530901	.002732240
367	134689	49430863	19.1572441	7.1595988	.002724796
368	135424	49836032	19.1833261	7.1660957	.002717391
369	136161	50243409	19.2093727	7.1725809	.002710027
370	136900	50653000	19.2353841	7.1790544	.002702703
371	137641	51064811	19.2613603	7.1855162	.002695418
372	138384	51478848	19.2873015	7.1919663	.002688172
373	139129	51895117	19.3132079	7.1984050	.002680965
374	139876	52313624	19.3390796	7.2048322	.002673797
375	140625	52734375	19.3649167	7.2112479	.002666667
376	141376	53157376	19.3907194	7.2176522	.002659574
377	142129	53582633	19.4164878	7.2240450	.002652520
378	142884	54010152	19.4422221	7.2304268	.002645503
379	143641	54439939	19.4679223	7.2367972	.002638522
380	144400	54872000	19.4935887	7.2431565	.002631579
381	145161	55306341	19.5192213	7.2495045	.002624672
382	145924	55742968	19.5448203	7.2558415	.002617801
383	146689	56181887	19.5703858	7.2621675	.002610966
384	147456	56623104	19.5959179	7.2684824	.002604167
385	148225	57066625	19.6214169	7.2747864	.002597403
386	148996	57512456	19.6468827	7.2810794	.002590674
387	149769	57960603	19.6723156	7.2873617	.002583979
388	150544	58411072	19.6977156	7.2936330	.002577320
389	151321	58863869	19.7230829	7.2998936	.002570694
390	152100	59319000	19.7484177	7.3061436	.002564103
391	152881	59776471	19.7737199	7.3123828	.002557545
392	153664	60236288	19.7989899	7.3186114	.002551020
393	154449	60698457	19.8242276	7.3248295	.002544529
394	155236	61162984	19.8494332	7.3310369	.002538071
395	156025	61629875	19.8746069	7.3372339	.002531646
396	156816	62099136	19.8997487	7.3434205	.002525253
397	157609	62570773	19.9248588	7.3495966	.002518892
398	158404	63044792	19.9499373	7.3557624	.002512563
399	159201	63521199	19.9749844	7.3619178	.002506266
400	160000	64000000	20.0000000	7.3680630	.002500000
401	160801	64481201	20.0249844	7.3741979	.002493766
402	161604	64964808	20.0499377	7.3803227	.002487562
403	162409	65450827	20.0748599	7.3864373	.002481390
404	163216	65939264	20.0997512	7.3925418	.002475248
405	164025	66430125	20.1246118	7.3986363	.002469136
406	164836	66923416	20.1494417	7.4047206	.002463054
407	165649	67419143	20.1742410	7.4107950	.002457002
408	166464	67917312	20.1990099	7.4168595	.002450980

SQUARES, CUBES, SQUARE ROOTS, CUBE ROOTS AND RECIPROCALS—(Continued)

No.	Squares	Cubes	Square roots	Cube roots	Reciprocals
409	167281	68417929	20.2237484	7.4229142	.002444988
410	168100	68921000	20.2484567	7.4289589	.002439024
411	168921	69426531	20.2731349	7.4349938	.002433090
412	169744	69934528	20.2977831	7.4410189	.002427184
413	170569	70444997	20.3224014	7.4470342	.002421308
414	171396	70957944	20.3469899	7.4530399	.002415459
415	172225	71473375	20.3715488	7.4590359	.002409639
416	173056	71991296	20.3960781	7.4650223	.002403846
417	173889	72511713	20.4205779	7.4709991	.002398082
418	174724	73034632	20.4450483	7.4769664	.002392344
419	175561	73560059	20.4694895	7.4829242	.002386635
420	176400	74088000	20.4939015	7.4888724	.002380952
421	177241	74618461	20.5182845	7.4948113	.002375297
422	178084	75151448	20.5426386	7.5007406	.002369668
423	178929	75686967	20.5669638	7.5066607	.002364066
424	179776	76225024	20.5912603	7.5125715	.002358491
425	180625	76765625	20.6155281	7.5184730	.002352941
426	181476	77308776	20.6397674	7.5243652	.002347418
427	182329	77854483	20.6639783	7.5302482	.002341920
428	183184	78402752	20.6881609	7.5361221	.002336449
429	184041	78953589	20.7123152	7.5419867	.002331002
430	184900	79507000	20.7364414	7.5478423	.002325581
431	185761	80062991	20.7605395	7.5536888	.002320186
432	186624	80621568	20.7846097	7.5595263	.002314815
433	187489	81182737	20.8086520	7.5653548	.002309469
434	188356	81746504	20.8326667	7.5711743	.002304147
435	189225	82312875	20.8566536	7.5769849	.002298851
436	190096	82881856	20.8806130	7.5827865	.002293578
437	190969	83453453	20.9045450	7.5885793	.002288330
438	191844	84027672	20.9284495	7.5943633	.002283105
439	192721	84604519	20.9523268	7.6001385	.002277904
440	193600	85184000	20.9761770	7.6059049	.002272727
441	194481	85766121	21.0000000	7.6116626	.002267574
442	195364	86350888	21.0237960	7.6174116	.002262443
443	196249	86938307	21.0475652	7.6231519	.002257336
444	197136	87528384	21.0713075	7.6288837	.002252252
445	198025	88121125	21.0950231	7.6346067	.002247191
446	198916	88716536	21.1187121	7.6403213	.002242152
447	199809	89314623	21.1423745	7.6460272	.002237136
448	200704	89915392	21.1660105	7.6517247	.002232143
449	201601	90518849	21.1896201	7.6574138	.002227171
450	202500	91125000	21.2132034	7.6630943	.002222222
451	203401	91733851	21.2367606	7.6687665	.002217295
452	204304	92345408	21.2602916	7.6744303	.002212389
453	205209	92959677	21.2837967	7.6800857	.002207506
454	206116	93576664	21.3072758	7.6857328	.002202643
455	207025	94196375	21.3307290	7.6913717	.002197802
456	207936	94818816	21.3541565	7.6970023	.002192982
457	208849	95443993	21.3775583	7.7026246	.002188184

SQUARES, CUBES, SQUARE ROOTS, CUBE ROOTS AND RECIPROCALS—(Continued)

No.	Squares	Cubes	Square roots	Cube roots	Reciprocals
458	209764	96071912	21.4009346	7.7082388	.002183406
459	210681	96702579	21.4242853	7.7138448	.002178649
460	211600	97336000	21.4476106	7.7194426	.002173913
461	212521	97972181	21.4709106	7.7250325	.002169197
462	213444	98611128	21.4941853	7.7306141	.002164502
463	214369	99252847	21.5174348	7.7361877	.002159827
464	215296	99897344	21.5406592	7.7417532	.002155172
465	216225	100544625	21.5638587	7.7473109	.002150538
466	217156	101194696	21.5870331	7.7528606	.002145923
467	218089	101847563	21.6101828	7.7584023	.002141328
468	219024	102503232	21.6333077	7.7639361	.002136752
469	219961	103161709	21.6564078	7.7694620	.002132196
470	220900	103823000	21.6794834	7.7749801	.002127660
471	221841	104487111	21.7025344	7.7804904	.002123142
472	222784	105154048	21.7255610	7.7859928	.002118644
473	223729	105823817	21.7485632	7.7914875	.002114165
474	224676	106496424	21.7715411	7.7969745	.002109705
475	225625	107171875	21.7944947	7.8024538	.002105263
476	226576	107850176	21.8174242	7.8079254	.002100840
477	227529	108531333	21.8403297	7.8133892	.002096436
478	228484	109215352	21.8632111	7.8188456	.002092050
479	229441	109902239	21.8860686	7.8242942	.002087683
480	230400	110592000	21.9089023	7.8297353	.002083333
481	231361	111284641	21.9317122	7.8351688	.002079002
482	232324	111980168	21.9544984	7.8405949	.002074689
483	233289	112678587	21.9772610	7.8460134	.002070393
484	234256	113379904	22.0000000	7.8514244	.002066116
485	235225	114084125	22.0227155	7.8568281	.002061856
486	236196	114791256	22.0454077	7.8622242	.002057613
487	237169	115501303	22.0680765	7.8676130	.002053388
488	238144	116214272	22.0907220	7.8729944	.002049180
489	239121	116930169	22.1133444	7.8783684	.002044990
490	240100	117649000	22.1359436	7.8837352	.002040816
491	241081	118370771	22.1585198	7.8890946	.002036660
492	242064	119095488	22.1810730	7.8944468	.002032520
493	243049	119823157	22.2036033	7.8997917	.002028398
494	244036	120553784	22.2261108	7.9051294	.002024291
495	245025	121287375	22.2485955	7.9104599	.002020202
496	246016	122023936	22.2710575	7.9157832	.002016129
497	247009	122763473	22.2934968	7.9210994	.002012072
498	248004	123505992	22.3159136	7.9264085	.002008032
499	249001	124251499	22.3383079	7.9317104	.002004008
500	250000	125000000	22.3606798	7.9370053	.002000000
501	251001	125751501	22.3830293	7.9422931	.001996008
502	252004	126506008	22.4053565	7.9475739	.001992032
503	253009	127263527	22.4276615	7.9528477	.001988072
504	254016	128024064	22.4499443	7.9581144	.001984127
505	255025	128787625	22.4722051	7.9633743	.001980198
506	256036	129554216	22.4944438	7.9686271	.001976285
507	257049	130323843	22.5166605	7.9738731	.001972387
508	258064	131096512	22.5388553	7.9791122	.001968504

SQUARES, CUBES, SQUARE ROOTS, CUBE ROOTS AND RECIPROCALS—(Continued)

No.	Squares	Cubes	Square roots	Cube roots	Reciprocals
509	259081	131872229	22.5610283	7.9843444	.001964637
510	260100	132651000	22.5831796	7.9895697	.001960784
511	261121	133432831	22.6053091	7.9947883	.001956947
512	262144	134217728	22.6274170	8.0000000	.001953125
513	263169	135005697	22.6495033	8.0052049	.001949318
514	264196	135796744	22.6715681	8.0104032	.001945525
515	265225	136590875	22.6936114	8.0155946	.001941748
516	266256	137388096	22.7156334	8.0207794	.001937984
517	267289	138188413	22.7376340	8.0259574	.001934236
518	268324	138991832	22.7596134	8.0311287	.001930502
519	269361	139798359	22.7815715	8.0362935	.001926782
520	270400	140608000	22.8035085	8.0414515	.001923077
521	271441	141420761	22.8254244	8.0466030	.001919386
522	272484	142236648	22.8473193	8.0517479	.001915709
523	273529	143055667	22.8691933	8.0568862	.001912046
524	274576	143877824	22.8910463	8.0620180	.001908397
525	275625	144703125	22.9128785	8.0671432	.001904762
526	276676	145531576	22.9346899	8.0722620	.001901141
527	277729	146363183	22.9564806	8.0773743	.001897533
528	278784	147197952	22.9782506	8.0824800	.001893939
529	279841	148035889	23.0000000	8.0875794	.001890359
530	280900	148877000	23.0217289	8.0926723	.001886792
531	281961	149721291	23.0434372	8.0977589	.001883239
532	283024	150568768	23.0651252	8.1028390	.001879699
533	284089	151419437	23.0867928	8.1079128	.001876173
534	285156	152273304	23.1084400	8.1129803	.001872659
535	286225	153130375	23.1300670	8.1180414	.001869159
536	287296	153990656	23.1516738	8.1230962	.001865672
537	288369	154854153	23.1732605	8.1281447	.001862197
538	289444	155720872	23.1948270	8.1331870	.001858736
539	290521	156590819	23.2163735	8.1382230	.001855288
540	291600	157464000	23.2379001	8.1432529	.001851852
541	292681	158340421	23.2594067	8.1482765	.001848429
542	293764	159220088	23.2808935	8.1532939	.001845018
543	294849	160103007	23.3023604	8.1583051	.001841621
544	295936	160989184	23.3238076	8.1633102	.001838235
545	297025	161878625	23.3452351	8.1683092	.001834862
546	298116	162771336	23.3666429	8.1733020	.001831502
547	299209	163667323	23.3880311	8.1782888	.001828154
548	300304	164566592	23.4093998	8.1832695	.001824818
549	301401	165469149	23.4307490	8.1882441	.001821494
550	302500	166375000	23.4520788	8.1932127	.001818182
551	303601	167284151	23.4733892	8.1981753	.001814882
552	304704	168196608	23.4946802	8.2031319	.001811594
553	305809	169112377	23.5159520	8.2080825	.001808318
554	306916	170031464	23.5372046	8.2130271	.001805054
555	308025	170953875	23.5584380	8.2179657	.001801802
556	309136	171879616	23.5796522	8.2228985	.001798561
557	310249	172808693	23.6008474	8.2278254	.001795332
558	311364	173741112	23.6220236	8.2327463	.001792115
559	312481	174676879	23.6431808	8.2376614	.001788909

SQUARES, CUBES, SQUARE ROOTS, CUBE ROOTS AND RECIPROCALS—(Continued)

No.	Squares	Cubes	Square roots	Cube roots	Reciprocals
560	313600	175616000	23.6643191	8.2425706	.001785714
561	314721	176558481	23.6854386	8.2474740	.001782531
562	315844	177504328	23.7065392	8.2523715	.001779359
563	316969	178453547	23.7276210	8.2572633	.001776199
564	318096	179406144	23.7486842	8.2621492	.001773050
565	319225	180362125	23.7697286	8.2670294	.001769912
566	320356	181321496	23.7907545	8.2719039	.001766784
567	321489	182284263	23.8117618	8.2767726	.001763668
568	322624	183250432	23.8327506	8.2816355	.001760563
569	323761	184220009	23.8537209	8.2864928	.001757469
570	324900	185193000	23.8746728	8.2913444	.001754386
571	326041	186169411	23.8956063	8.2961903	.001751313
572	327184	187149248	23.9165215	8.3010304	.001748252
573	328329	188132517	23.9374184	8.3058651	.001745201
574	329476	189119224	23.9582971	8.3106941	.001742160
575	330625	190109375	23.9791576	8.3155175	.001739130
576	331776	191102976	24.0000000	8.3203353	.001736111
577	332929	192100033	24.0208243	8.3251475	.001733102
578	334084	193100552	24.0416306	8.3299542	.001730104
579	335241	194104539	24.0624188	8.3347553	.001727116
580	336400	195112000	24.0831891	8.3395509	.001724138
581	337561	196122941	24.1039416	8.3443410	.001721170
582	338724	197137368	24.1246762	8.3491256	.001718213
583	339889	198155287	24.1453929	8.3539047	.001715266
584	341056	199176704	24.1660919	8.3586784	.001712329
585	342225	200201625	24.1867732	8.3634466	.001709402
586	343396	201230056	24.2074369	8.3682095	.001706485
587	344569	202262003	24.2280829	8.3729668	.001703578
588	345744	203297472	24.2487113	8.3777188	.001700680
589	346921	204336469	24.2693222	8.3824653	.001697793
590	348100	205379000	24.2899156	8.3872065	.001694915
591	349281	206425071	24.3104916	8.3919423	.001692047
592	350464	207474688	24.3310501	8.3966729	.001689189
593	351649	208527857	24.3515913	8.4013981	.001686341
594	352836	209584584	24.3721152	8.4061180	.001683502
595	354025	210644875	24.3926218	8.4108326	.001680672
596	355216	211708736	24.4131112	8.4155419	.001677852
597	356409	212776173	24.4335834	8.4202460	.001675042
598	357604	213847192	24.4540385	8.4249448	.001672241
599	358801	214921799	24.4744765	8.4296383	.001669449
600	360000	216000000	24.4948974	8.4343267	.001666667
601	361201	217081801	24.5153013	8.4390098	.001663894
602	362404	218167208	24.5356883	8.4436877	.001661130
603	363609	219256227	24.5560583	8.4483605	.001658375
604	364816	220348864	24.5764115	8.4530281	.001655629
605	366025	221445125	24.5967478	8.4576906	.001652893
606	367236	222545016	24.6170673	8.4623479	.001650165
607	368449	223648543	24.6373700	8.4670001	.001647446
608	369664	224755712	24.6576560	8.4716471	.001644737
609	370881	225866529	24.6779254	8.4762892	.001642036
610	372100	226981000	24.6981781	8.4809261	.001639344

SQUARES, CUBES, SQUARE ROOTS, CUBE ROOTS AND RECIPROCALS—(Continued)

No.	Squares	Cubes	Square roots	Cube roots	Reciprocals
611	373321	228099131	24.7184142	8.4855579	.001636661
612	374544	229220928	24.7386338	8.4901848	.001633987
613	375769	230346397	24.7588368	8.4948065	.001631321
614	376996	231475544	24.7790234	8.4994233	.001628664
615	378225	232608375	24.7991935	8.5040350	.001626016
616	379456	233744896	24.8193473	8.5086417	.001623377
617	380689	234885113	24.8394847	8.5132435	.001620746
618	381924	236029032	24.8596058	8.5178403	.001618123
619	383161	237176659	24.8797106	8.5224321	.001615509
620	384400	238328000	24.8997992	8.5270189	.001612903
621	385641	239483061	24.9198716	8.5316009	.001610306
622	386884	240641848	24.9399278	8.5361780	.001607717
623	388129	241804367	24.9599679	8.5407501	.001605136
624	389376	242970624	24.9799920	8.5453173	.001602564
625	390625	244140625	25.0000000	8.5498797	.001600000
626	391876	245314376	25.0199920	8.5544372	.001597444
627	393129	246491883	25.0399681	8.5589899	.001594896
628	394384	247673152	25.0599282	8.5635377	.001592357
629	395641	248858189	25.0798724	8.5680807	.001589825
630	396900	250047000	25.0998008	8.5726189	.001587302
631	398161	251239591	25.1197134	8.5771523	.001584786
632	399424	252435968	25.1396102	8.5816809	.001582278
633	400689	253636137	25.1594913	8.5862047	.001579779
634	401956	254840104	25.1793566	8.5907238	.001577287
635	403225	256047875	25.1992063	8.5952380	.001574803
636	404496	257259456	25.2190404	8.5997476	.001572327
637	405769	258474853	25.2388589	8.6042525	.001569859
638	407044	259694072	25.2586619	8.6087526	.001567398
639	408321	260917119	25.2784493	8.6132480	.001564945
640	409600	262144000	25.2982213	8.6177388	.001562500
641	410881	263374721	25.3179778	8.6222248	.001560062
642	412164	264609288	25.3377189	8.6267063	.001557632
643	413449	265847707	25.3574447	8.6311830	.001555210
644	414736	267089984	25.3771551	8.6356551	.001552795
645	416025	268336125	25.3968502	8.6401226	.001550388
646	417316	269586136	25.4165301	8.6445855	.001547988
647	418609	270840023	25.4361947	8.6490437	.001545595
648	419904	272097792	25.4558441	8.6534974	.001543210
649	421201	273359449	25.4754784	8.6579465	.001540832
650	422500	274625000	25.4950976	8.6623911	.001538462
651	423801	275894451	25.5147016	8.6668310	.001536098
652	425104	277167808	25.5342907	8.6712665	.001533742
653	426409	278445077	25.5538647	8.6756974	.001531394
654	427716	279726264	25.5734237	8.6801237	.001529052
655	429025	281011375	25.5929678	8.6845456	.001526718
656	430336	282300416	25.6124969	8.6889630	.001524390
657	431649	283593393	25.6320112	8.6933759	.001522070
658	432964	284890312	25.6515107	8.6977843	.001519757
659	434281	286191179	25.6709953	8.7021882	.001517451
660	435600	287496000	25.6904652	8.7065877	.001515152
661	436921	288804781	25.7099203	8.7109827	.001512859

SQUARES, CUBES, SQUARE ROOTS, CUBE ROOTS AND RECIPROCALS—(Continued)

No.	Squares	Cubes	Square roots	Cube roots	Reciprocals
662	438244	290117528	25.7293607	8.7153734	.001510574
663	439569	291434247	25.7487864	8.7197596	.001508296
664	440896	292754944	25.7681975	8.7241414	.001506024
665	442225	294079625	25.7875939	8.7285187	.001503759
666	443556	295408296	25.8069758	8.7328918	.001501502
667	444889	296740963	25.8263431	8.7372604	.001499250
668	446224	298077632	25.8456960	8.7416246	.001497006
669	447561	299418309	25.8650343	8.7459846	.001494768
670	448900	300763000	25.8843582	8.7503401	.001492537
671	450241	302111711	25.9036677	8.7546913	.001490313
672	451584	303464448	25.9229628	8.7590383	.001488095
673	452929	304821217	25.9422435	8.7633809	.001485884
674	454276	306182024	25.9615100	8.7677192	.001483680
675	455625	307546875	25.9807621	8.7720532	.001481481
676	456976	308915776	26.0000000	8.7763830	.001479290
677	458329	310288733	26.0192237	8.7807084	.001477105
678	459684	311665752	26.0384331	8.7850296	.001474926
679	461041	313046839	26.0576284	8.7893466	.001472754
680	462400	314432000	26.0768096	8.7936593	.001470588
681	463761	315821241	26.0959767	8.7979679	.001468429
682	465124	317214568	26.1151297	8.8022721	.001466276
683	466489	318611987	26.1342687	8.8065722	.001464129
684	467856	320013504	26.1533937	8.8108681	.001461988
685	469225	321419125	26.1725047	8.8151598	.001459854
686	470596	322828856	26.1916017	8.8194474	.001457726
687	471969	324242703	26.2106848	8.8237307	.001455604
688	473344	325660672	26.2297541	8.8280099	.001453488
689	474721	327082769	26.2488095	8.8322850	.001451379
690	476100	328509000	26.2678511	8.8365559	.001449275
691	477481	329939371	26.2868789	8.8408227	.001447178
692	478864	331373888	26.3058929	8.8450854	.001445087
693	480249	332812557	26.3248932	8.8493440	.001443001
694	481636	334255384	26.3438797	8.8535985	.001440922
695	483025	335702375	26.3628527	8.8578489	.001438849
696	484416	337153536	26.3818119	8.8620952	.001436782
697	485809	338608873	26.4007576	8.8663375	.001434720
698	487204	340068392	26.4196896	8.8705757	.001432665
699	488601	341532099	26.4386081	8.8748099	.001430615
700	490000	343000000	26.4575131	8.8790400	.001428571
701	491401	344472101	26.4764046	8.8832661	.001426534
702	492804	345948408	26.4952826	8.8874882	.001424501
703	494209	347428927	26.5141472	8.8917063	.001422475
704	495616	348913664	26.5329983	8.8959204	.001420455
705	497025	350402625	26.5518361	8.9001304	.001418440
706	498436	351895816	26.5706605	8.9043366	.001416431
707	499849	353393243	26.5894716	8.9085387	.001414427
708	501264	354894912	26.6082694	8.9127369	.001412429
709	502681	356400829	26.6270539	8.9169311	.001410437
710	504100	357911000	26.6458252	8.9211214	.001408451
711	505521	359425431	26.6645833	8.9253078	.001406470
712	506944	360944128	26.6833281	8.9294902	.001404494

SQUARES, CUBES, SQUARE ROOTS, CUBE ROOTS AND RECIPROCALS—(Continued)

No.	Squares	Cubes	Square roots	Cube roots	Reciprocals
713	508369	362467097	26.7020598	8.9336687	.001402525
714	509796	363994344	26.7207784	8.9378433	.001400560
715	511225	365525875	26.7394839	8.9420140	.001398601
716	512656	367061696	26.7581763	8.9461809	.001396648
717	514089	368601813	26.7768557	8.9503438	.001394700
718	515524	370146232	26.7955220	8.9545029	.001392758
719	516961	371694959	26.8141754	8.9586581	.001390821
720	518400	373248000	26.8328157	8.9628095	.001388889
721	519841	374805361	26.8514432	8.9669570	.001386963
722	521284	376367048	26.8700577	8.9711007	.001385042
723	522729	377933067	26.8886593	8.9752406	.001383126
724	524176	379503424	26.9072481	8.9793766	.001381215
725	525625	381078125	26.9258240	8.9835089	.001379310
726	527076	382657176	26.9443872	8.9876373	.001377410
727	528529	384240583	26.9629375	8.9917620	.001375516
728	529984	385828352	26.9814751	8.9958829	.001373626
729	531441	387420489	27.0000000	9.0000000	.001371742
730	532900	389017000	27.0185122	9.0041134	.001369863
731	534361	390617891	27.0370117	9.0082229	.001367989
732	535824	392223168	27.0554985	9.0123288	.001366120
733	537289	393832837	27.0739727	9.0164309	.001364256
734	538756	395446904	27.0924344	9.0205293	.001362398
735	540225	397065375	27.1108834	9.0246239	.001360544
736	541696	398688256	27.1293199	9.0287149	.001358696
737	543169	400315553	27.1477439	9.0328021	.001356852
738	544644	401947272	27.1661554	9.0368857	.001355014
739	546121	403583419	27.1845544	9.0409655	.001353180
740	547600	405224000	27.2029410	9.0450417	.001351351
741	549081	406869021	27.2213152	9.0491142	.001349528
742	550564	408518488	27.2396769	9.0531831	.001347709
743	552049	410172407	27.2580263	9.0572482	.001345895
744	553536	411830784	27.2763634	9.0613098	.001344086
745	555025	413493625	27.2946881	9.0653677	.001342282
746	556516	415160936	27.3130006	9.0694220	.001340483
747	558009	416832723	27.3313007	9.0734726	.001338688
748	559504	418508992	27.3495887	9.0775197	.001336898
749	561001	420189749	27.3678644	9.0815631	.001335113
750	562500	421875000	27.3861279	9.0856030	.001333333
751	564001	423564751	27.4043792	9.0896392	.001331558
752	565504	425259008	27.4226184	9.0936719	.001329787
753	567009	426957777	27.4408455	9.0977010	.001328021
754	568516	428661064	27.4590604	9.1017265	.001326260
755	570025	430368875	27.4772633	9.1057485	.001324503
756	571536	432081216	27.4954542	9.1097669	.001322751
757	573049	433798093	27.5136330	9.1137818	.001321004
758	574564	435519512	27.5317998	9.1177931	.001319261
759	576081	437245479	27.5499546	9.1218010	.001317523
760	577600	438976000	27.5680975	9.1258053	.001315789
761	579121	440711081	27.5862284	9.1298061	.001314060
762	580644	442450728	27.6043475	9.1338034	.001312336
763	582169	444194947	27.6224546	9.1377971	.001310616

SQUARES, CUBES, SQUARE ROOTS, CUBE ROOTS AND RECIPROCALS—(Continued)

No.	Squares	Cubes	Square roots	Cube roots	Reciprocals
764	583696	445943744	27.6405499	9.1417874	.001308901
765	585225	447697125	27.6586334	9.1457742	.001307100
766	586756	449455096	27.6767050	9.1497576	.001305483
767	588289	451217663	27.6947648	9.1537375	.001303781
768	589824	452984832	27.7128129	9.1577139	.001302083
769	591361	454756609	27.7308492	9.1616869	.001300390
770	592900	456533000	27.7488739	9.1656565	.001298701
771	594441	458314011	27.7668868	9.1696225	.001297017
772	595984	460099648	27.7848880	9.1735852	.001295337
773	597529	461889917	27.8028775	9.1775445	.001293661
774	599076	463684824	27.8208555	9.1815003	.001291990
775	600625	465484375	27.8388218	9.1854527	.001290323
776	602176	467288576	27.8567766	9.1894018	.001288660
777	603729	469097433	27.8747197	9.1933474	.001287001
778	605284	470910952	27.8926514	9.1972897	.001285347
779	606841	472729139	27.9105715	9.2012286	.001283697
780	608400	474552000	27.9284801	9.2051641	.001282051
781	609961	476379541	27.9463772	8.2090962	.001280410
782	611524	478211768	27.9642629	9.2130250	.001278772
783	613089	480048687	27.9821372	9.2169505	.001277139
784	614656	481890304	28.0000000	8.2208726	.001275510
785	616225	483736625	28.0178515	9.2247914	.001273885
786	617796	485587656	28.0356915	9.2287068	.001272265
787	619369	487443403	28.0535203	9.2326189	.001270648
788	620944	489303872	28.0713377	9.2365277	.001269036
789	622521	491169069	28.0891438	9.2404333	.001267427
790	624100	493039000	28.1069386	9.2443355	.001265823
791	625681	494913671	28.1247222	9.2482344	.001264223
792	627264	496793088	28.1424946	9.2521300	.001262626
793	628849	498677257	28.1602557	9.2560224	.001261034
794	630436	500566184	28.1780056	9.2599114	.001259446
795	632025	502459875	28.1957444	9.2637973	.001257862
796	633616	504358336	28.2134720	9.2676798	.001256281
797	635209	506261573	28.2311884	9.2715592	.001254705
798	636804	508169592	28.2488938	9.2754352	.001253133
799	638401	510082399	28.2665881	9.2793081	.001251564
800	640000	512000000	28.2842712	9.2831777	.001250000
801	641601	513922401	28.3019434	9.2870440	.001248439
802	643204	515849608	28.3196045	9.2909072	.001246883
803	644809	517781627	28.3372546	9.2947671	.001245330
804	646416	519718464	28.3548938	9.2986239	.001243781
805	648025	521660125	28.3725219	9.3024775	.001242236
806	649636	523606616	28.3901391	9.3063278	.001240695
807	651249	525557943	28.4077454	9.3101750	.001239157
808	652864	527514112	28.4253408	9.3140190	.001237624
809	654481	529475129	28.4429253	9.3178599	.001236094
810	656100	531441000	28.4604989	9.3216975	.001234568
811	657721	533411731	28.4780617	9.3255320	.001233046
812	659344	535387328	28.4956137	9.3293634	.001231527
813	660969	537367797	28.5131549	9.3331916	.001230012
814	662596	539353144	28.5306852	9.3370167	.001228501

SQUARES, CUBES, SQUARE ROOTS, CUBE ROOTS AND RECIPROCALS—(Continued)

No.	Squares	Cubes	Square roots	Cube roots	Reciprocals
815	664225	541343375	28.5482048	9.3408386	.001226994
816	665856	543338496	28.5657137	9.3446575	.001225490
817	667489	545338513	28.5832119	9.3484731	.001223990
818	669124	547343432	28.6006993	9.3522857	.001222494
819	670761	549353259	28.6181760	9.3560952	.001221001
820	672400	551368000	28.6356421	9.3599016	.001219512
821	674041	553387661	28.6530976	9.3637049	.001218027
822	675684	555412248	28.6705424	9.3675051	.001216545
823	677329	557441767	28.6879766	9.3713022	.001215067
824	678976	559476224	28.7054002	9.3750963	.001213592
825	680625	561515625	28.7228132	9.3788873	.001212121
826	682276	563559976	28.7402157	9.3826752	.001210654
827	683929	565609283	28.7576077	9.3864600	.001209190
828	685584	567663552	28.7749891	9.3902419	.001207729
829	687241	569722789	28.7923601	9.3940206	.001206273
830	688900	571787000	28.8097206	9.3977964	.001204819
831	690561	573856191	28.8270706	9.4015691	.001203369
832	692224	575930368	28.8444102	9.4053387	.001201923
833	693889	578009537	28.8617394	9.4091054	.001200480
834	695556	580093704	28.8790582	9.4128690	.001199041
835	697225	582182875	28.8963666	9.4166297	.001197605
836	698896	584277056	28.9136646	9.4203873	.001196172
837	700569	586376253	28.9309523	9.4241420	.001194743
838	702244	588480472	28.9482297	9.4278936	.001193317
839	703921	590589719	28.9654967	9.4316423	.001191895
840	705600	592704000	28.9827535	9.4353880	.001190476
841	707281	594823321	29.0000000	9.4391307	.001189061
842	708964	596947688	29.0172363	9.4428704	.001187648
843	710649	599077107	29.0344623	9.4466072	.001186240
844	712336	601211584	29.0516781	9.4503410	.001184834
845	714025	603351125	29.0688837	9.4540719	.001183432
846	715716	605495736	29.0860791	9.4577999	.001182033
847	717409	607645423	29.1032644	9.4615249	.001180638
848	719104	609800192	29.1204396	9.4652470	.001179245
849	720801	611960049	29.1376046	9.4689661	.001177856
850	722500	614125000	29.1547595	9.4726824	.001176471
851	724201	616295051	29.1719043	9.4763957	.001175088
852	725904	618470208	29.1890390	9.4801061	.001173709
853	727609	620650477	29.2061637	9.4838136	.001172333
854	729316	622835864	29.2232784	9.4875182	.001170960
855	731025	625026375	29.2403830	9.4912200	.001169591
856	732736	627222016	29.2574777	9.4949188	.001168224
857	734449	629422793	29.2745623	9.4986147	.001166861
858	736164	631628712	29.2916370	9.5023078	.001165501
859	737881	633839779	29.3087018	9.5059980	.001164144
860	739600	636056000	29.3257566	9.5096854	.001162791
861	741321	638277381	29.3428015	9.5133699	.001161440
862	743044	640503928	29.3598365	9.5170515	.001160093
863	744769	642735647	29.3768616	9.5207303	.001158749
864	746496	644972544	29.3938769	9.5244063	.001157407
865	748225	647214625	29.4108823	9.5280794	.001156069

SQUARES, CUBES, SQUARE ROOTS, CUBE ROOTS AND RECIPROCALS—(Continued)

No.	Squares	Cubes	Square roots	Cube roots	Reciprocals
866	749956	649461896	29.4278779	9.5317497	.001154734
867	751689	651714363	29.4448637	9.5354172	.001153403
868	753424	653972032	29.4618397	9.5390818	.001152074
869	755161	656234909	29.4788059	9.5427437	.001150748
870	756900	658503000	29.4957624	9.5464027	.001149425
871	758641	660776311	29.5127091	9.5500589	.001148106
872	760384	663054848	29.5296461	9.5537123	.001146789
873	762129	665338617	29.5465734	9.5573630	.001145475
874	763876	667627624	29.5634910	9.5610108	.001144165
875	765625	669921875	29.5803989	9.5646559	.001142857
876	767376	672221376	29.5972972	9.5682982	.001141553
877	769129	674526133	29.6141858	9.5719377	.001140251
878	770884	676836152	29.6310648	9.5755745	.001138952
879	772641	679151439	29.6479342	9.5792085	.001137656
880	774400	681472000	29.6647939	9.5828397	.001136364
881	776161	683797841	29.6816442	9.5864682	.001135074
882	777924	686128968	29.6984848	9.5900939	.001133787
883	779689	688465387	29.7153159	9.5937169	.001132503
884	781456	690807104	29.7321375	9.5973373	.001131222
885	783225	693154125	29.7489496	9.6009548	.001129944
886	784996	695506456	29.7657521	9.6045696	.001128668
887	786769	697864103	29.7825452	9.6081817	.001127396
888	788544	700227072	29.7993289	9.6117911	.001126126
889	790321	702595369	29.8161030	9.6153977	.001124859
890	792100	704969000	29.8328678	9.6190017	.001123596
891	793881	707347971	29.8496231	9.6226030	.001122334
892	795664	709732288	29.8663690	9.6262016	.001121076
893	797449	712121957	29.8831056	9.6297975	.001119821
894	799236	714516984	29.8998328	9.6333907	.001118568
895	801025	716917375	29.9165506	9.6369812	.001117318
896	802816	719323136	29.9332591	9.6405690	.001116071
897	804609	721734273	29.9499583	9.6441542	.001114827
898	806404	724150792	29.9666481	9.6477367	.001113586
899	808201	726572699	29.9833287	9.6513166	.001112347
900	810000	729000000	30.0000000	9.6548938	.001111111
901	811801	731432701	30.0166620	9.6584684	.001109878
902	813604	733870808	30.0333148	9.6620403	.001108647
903	815409	736314327	30.0499584	9.6656096	.001107420
904	817216	738763264	30.0665928	9.6691762	.001106195
905	819025	741217625	30.0832179	9.6727403	.001104972
906	820836	743677416	30.0998339	9.6763017	.001103753
907	822649	746142643	30.1164407	9.6798604	.001102536
908	824464	748613312	30.1330383	9.6834166	.001101322
909	826281	751089429	30.1496269	9.6869701	.001100110
910	828100	753571000	30.1662063	9.6905211	.001098901
911	829921	756058031	30.1827765	9.6940694	.001097695
912	831744	758550528	30.1993377	9.6976151	.001096491
913	833569	761048497	30.2158899	9.7011583	.001095290
914	835396	763551944	30.2324329	9.7046989	.001094092
915	837225	766060875	30.2489669	9.7082369	.001092896
916	839056	768575296	30.2654919	9.7117723	.001091703

SQUARES, CUBES, SQUARE ROOTS, CUBE ROOTS AND RECIPROCALS—(Continued)

No.	Squares	Cubes	Square roots	Cube roots	Reciprocals
917	840889	771095213	30.2820079	9.7153051	.001090513
918	842724	773620632	30.2985148	9.7188354	.001089325
919	844561	776151559	30.3150128	9.7223631	.001088139
920	846400	778688000	30.3315018	9.7258883	.001086957
921	848241	781229961	30.3479818	9.7294109	.001085776
922	850084	783777448	30.3644529	9.7329309	.001084599
923	851929	786330467	30.3809151	9.7364484	.001083424
924	853776	788889024	30.3973683	9.7399634	.001082251
925	855625	791453125	30.4138127	9.7434758	.001081081
926	857476	794022776	30.4302481	9.7469857	.001079914
927	859329	796597983	30.4466747	9.7504930	.001078749
928	861184	799178752	30.4630924	9.7539979	.001077586
929	863041	801765089	30.4795013	9.7575002	.001076426
930	864900	804357000	30.4959014	9.7610001	.001075269
931	866761	806954491	30.5122926	9.7644974	.001074114
932	868624	809557568	30.5286750	9.7679922	.001072961
933	870489	812166237	30.5450487	9.7714845	.001071811
934	872356	814780504	30.5614136	9.7749743	.001070664
935	874225	817400375	30.5777697	9.7784616	.001069519
936	876096	820025856	30.5941171	9.7819466	.001068376
937	877969	822656953	30.6104557	9.7854288	.001067236
938	879844	825293672	30.6267857	9.7889087	.001066098
939	881721	827936019	30.6431069	9.7923861	.001064963
940	883600	830584000	30.6594194	9.7958611	.001063830
941	885481	833237621	30.6757233	9.7993336	.001062699
942	887364	835896888	30.6920185	9.8028036	.001061571
943	889249	838561807	30.7083051	9.8062711	.001060445
944	891136	841232384	30.7245830	9.8097362	.001059322
945	893025	843908625	30.7408523	9.8131989	.001058201
946	894916	846590536	30.7571130	9.8166591	.001057082
947	896809	849278133	30.7733651	9.8201169	.001055966
948	898704	851971392	30.7896086	9.8235723	.001054852
949	900601	854670349	30.8058436	9.8270252	.001053741
950	902500	857375000	30.8220700	9.8304757	.001052632
951	904401	860085351	30.8382879	9.8339238	.001051525
952	906304	862801408	30.8544972	9.8373695	.001050420
953	908209	865523177	30.8706981	9.8408127	.001049318
954	910116	868250664	30.8868904	9.8442536	.001048218
955	912025	870983875	30.9030743	9.8476920	.001047120
956	913936	873722816	30.9192497	9.8511280	.001046025
957	915849	876467493	30.9354166	9.8545617	.001044932
958	917764	879217912	30.9515751	9.8579929	.001043841
959	919681	881974079	30.9677251	9.8614218	.001042753
960	921600	884736000	30.9838668	9.8648483	.001041667
961	923521	887503681	31.0000000	9.8682724	.001040583
962	925444	890277128	31.0161248	9.8716941	.001039501
963	927369	893056347	31.0322413	9.8751135	.001038422
964	929296	895841344	31.0483494	9.8785305	.001037344
965	931225	898632125	31.0644491	9.8819451	.001036269
966	933156	901428696	31.0805405	9.8853574	.001035197
967	935089	904231063	31.0966236	9.8887673	.001034126

SQUARES, CUBES, SQUARE ROOTS, CUBE ROOTS AND RECIPROCALS—(Continued)

No.	Squares	Cubes	Square roots	Cube roots	Reciprocals
968	937024	907039232	31.1126984	9.8921749	.001033058
969	938961	909853209	31.1287648	9.8955801	.001031992
970	940900	912673000	31.1448230	9.8989830	.001030928
971	942841	915498611	31.1608729	9.9023835	.001029866
972	944784	918330048	31.1769145	9.9057817	.001028807
973	946729	921167317	31.1929479	9.9091776	.001027749
974	948676	924010424	31.2089731	9.9125712	.001026694
975	950625	926859375	31.2249900	9.9159624	.001025641
976	952576	929714176	31.2409987	9.9193513	.001024590
977	954529	932574833	31.2569992	9.9227379	.001023541
978	956484	935441352	31.2729915	9.9261222	.001022495
979	958441	938313739	31.2889757	9.9295042	.001021450
980	960400	941192000	31.3049517	9.9328839	.001020408
981	962361	944076141	31.3209195	9.9362613	.001019368
982	964324	946966168	31.3368792	9.9396363	.001018330
983	966289	949862087	31.3528308	9.9430092	.001017294
984	968256	952763904	31.3687743	9.9463797	.001016260
985	970225	955671625	31.3847097	9.9497479	.001015228
986	972196	958585256	31.4006369	9.9531138	.001014199
987	974169	961504803	31.4165561	9.9564775	.001013171
988	976144	964430272	31.4324673	9.9598389	.001012146
989	978121	967361669	31.4483704	9.9631981	.001011122
990	980100	970299000	31.4642654	9.9665549	.001010101
991	982081	973242271	31.4801525	9.9699095	.001009082
992	984064	976191488	31.4960315	9.9732619	.001008065
993	986049	979146657	31.5119025	9.9766120	.001007049
994	988036	982107784	31.5277655	9.9799599	.001006036
995	990025	985074875	31.5436206	9.9833055	.001005025
996	992016	988047936	31.5594677	9.9866488	.001004016
997	994009	991026973	31.5753068	9.9899900	.001003009
998	996004	994011992	31.5911380	9.9933289	.001002004
999	998001	997002999	31.6069613	9.9966656	.001001001
1000	1000000	1000000000	31.6227766	10.0000000	.001000000
1001	1002001	1003003001	31.6385840	10.0033322	.0009990010
1002	1004004	1006012008	31.6543836	10.0066622	.0009980040
1003	1006009	1009027027	31.6701752	10.0099899	.0009970090
1004	1008016	1012048064	31.6859590	10.0133155	.0009960159
1005	1010025	1015075125	31.7017349	10.0166389	.0009950249
1006	1012036	1018108216	31.7175030	10.0199601	.0009940358
1007	1014049	1021147343	31.7332633	10.0232791	.0009930487
1008	1016064	1024192512	31.7490157	10.0265958	.0009920635
1009	1018081	1027243729	31.7647603	10.0299104	.0009910803
1010	1020100	1030301000	31.7804972	10.0332228	.0009900990
1011	1022121	1033364331	31.7962262	10.0365330	.0009891197
1012	1024144	1036433728	31.8119474	10.0398410	.0009881423
1013	1026169	1039509197	31.8276609	10.0431469	.0009871668
1014	1028196	1042590744	31.8433666	10.0464506	.0009861933
1015	1030225	1045678375	31.8590646	10.0497521	.0009852217
1016	1032256	1048772096	31.8747549	10.0530514	.0009842520
1017	1034289	1051871913	31.8904374	10.0563485	.0009832842
1018	1036324	1054977832	31.9061123	10.0596435	.0009823183
1019	1038361	1058089859	31.9217794	10.0629364	.0009813543

SECTION XII

DEFINITIONS

DEFINITIONS

A

A. C.: Abbreviation for alternating current.

Accumulator: Storage battery.

Alternating Current: Current which flows alternately in opposite directions in a circuit.

Alternator: A machine for generating alternating current.

Ammeter: An instrument for measuring electric current (amperes).

Ampere: The unit of electric current. The rate of flow of electricity in a circuit is measured in amperes. An ampere is such a rate of flow as will deposit 0.001118 grams of silver per second from a standard solution of silver nitrate.

Ampere-Hour: A unit of quantity of electric flow. One ampere flowing for one hour is a quantity of flow equal to one ampere-hour. One ampere-hour is equal to 3600 coulombs.

Ampere-Turn: A unit of magnetizing force. It is that magnetizing force which is given by one turn of a coil carrying one ampere.

Angle of Incidence: The angle which a ray of light striking a surface makes with the normal to that surface.

Angle of Reflection: The angle at which a ray of light leaves a surface where it has been reflected, with respect to the normal.

Armature: One of the two main circuits which compose the windings of a generator or motor (the rotating winding on a D. C. machine; the distributed winding which may be either stationary or rotating, on an A. C. machine.)

Auto-Transformer: A transformer with a single winding where the secondary circuit consists of a part of the winding of the primary circuit.

B

Battery: A cell or cells which develop an electromotive-force and are used for converting chemical energy into electrical energy.

Booster: A low voltage direct current generator which is connected in series with feeders in order to raise the voltage.

British Thermal Unit: A unit of heat energy. It is equivalent to the heat required to raise the temperature of one pound of water one degree Fahrenheit.

B. T. U.: Abbreviation for British Thermal Unit.

Bus-Bars: The bars on the back of a switchboard which may be connected by means of switches to any or all the incoming and outgoing circuits.

C

C.: The abbreviation which was formerly used instead of I, to represent the current in a circuit.

It is also the abbreviation for Centigrade.

C.-P.: The abbreviation for candle-power.

Candle-Power: The luminous intensity of a light giving source in a particular direction.

Cathode: The negative electrode of an electrolytic cell or of a vapor lamp.

Centigrade: The system of temperature graduation designed by the French. Zero on the Centigrade scale is the freezing temperature of water and 100 degrees is the boiling point. Degree Centigrade equals degrees Fahrenheit less 32 and multiplied by 5/9.

C. g. s.: Abbreviation for centimeter-gram-second, which is the name applied to the system of units built up from these as fundamentals.

Circuit: A complete conductive path for electric flow.

Circuit-Breaker: A device which automatically opens an electric circuit when certain limits of current are exceeded.

Circular Mil: A unit of cross sectional area of wires. A cylindrical conductor one thousandth of an inch in diameter has a cross section of one circular mil. The cross section in circular mils of any cylindrical conductor is equal to its diameter, in thousandths of an inch, squared.

Color: The sensation in the eye is affected by the wave length or the combination of wave lengths of the light falling upon the retina.

Commutator: Any mechanical device for quickly changing the direction of flow in an electric circuit.

Compound Electrical Machines: Those having in addition to the shunt field circuit a field circuit connected in series with the line taking current from, or supplying current to the machine.

Conductivity: The property of a material which enables it to conduct electrical current. It is measured by the reciprocal of the resistance and the unit has been called the "mho."

Conductor: A body which carries electric current.

Conduit: An iron duct or pipe through which wires may be run.

Constant Current: A current whose value does not vary with changes of conditions in the circuit. A system having a "constant current."

Constant Voltage: A term applied to an electric system which is maintained at a state of constant electrical pressure.

Continuous Current: Current which flows in only one direction in a circuit. Direct current.

Copper Loss: The term applied to the power lost in the conductors of electric machinery; also called the I^2R loss.

Cosine: A function of an angle. It is the ratio of the shorter to the longer of its bounding lines when a right triangle is formed by drawing a line from any point on one side and perpendicular to the other side.

Coulomb: The unit of quantity of electric flow. One ampere flowing for one second is a coulomb of electric flow.

Current: The rate of flow of electricity. Current is commonly measured in amperes.

D

Depreciation: The falling off in value of a piece of apparatus as it is used. Depreciation charges are usually made so that the apparatus may be paid for by the time it has to be replaced.

Diffusion: Light is said to be diffused when by process of reflection and refraction it reaches the eye from many directions rather than from the one direction of the source. Diffusion of light is therefore a process of reducing the intrinsic brilliancy of the source.

Direct Current: Current which flows continually in one direction. Continuous current.

Distribution: The variation of the mean zonal candle-power of a source, in the various angles with respect to the vertical axis.

Distribution Curve: A polar diagram showing graphically the distribution of a light giving source.

Drop: The fall in voltage in a current carrying conductor.

E

Edison Three-Wire System: A three-wire system supplied by two machines connected in series, or their equivalent. The so-called neutral wire is connected to the junction of the two machines, thereby rendering two voltages available, one twice the other, and furnishing the advantage of transmission at double the voltage of the receiver.

Electrode: A terminal of an electric circuit, as the metallic plates of batteries and the carbons of arc lamps.

Electrolysis: The separation of a chemical compound into its elements by means of an electric current.

Electrolyte: A liquid which is used as a conductor of electric current: The liquid of an electric cell.

Electromotive Force: Difference of potential or electric pressure. Voltage.

F

Farad: A unit of electric capacity. A condenser is said to have a capacity of one farad when 1 volt produces on it a charge of 1 coulomb.

Flux: A flow of radiant energy from a source. The total emanation of light is called the total flux of light.

The lines of strain present in a magnetic field.

Foot-Candle: A unit of illumination and equal to that received by a surface every point of which is one foot distant from a source of one candle-power intensity; that is to say, one lumen per square foot gives an average intensity of one foot candle.

G

Generator: A machine which produces electromotive force by the rotation of a number of conductors in a magnetic field; used to convert mechanical energy into electrical energy.

Ground: A contact, usually accidental, between an electric circuit and its supporting frame work.

The connection of an electric circuit to the earth.

H

Horse-power: A unit of power. The ability to raise 550 pounds one foot in one second or the equivalent thereof. Equivalent, therefore, to 550 ft. lbs. per second or 33,000 ft. lbs. per minute.

I

Illumination: A measure of the light received per unit of area on any given surface. The unit of illumination most frequently used is the foot-candle.

Insulation: Material which has so low a conductivity as to be practically a non-conductor.

Intensity: See Luminous Intensity.

Intrinsic Brilliancy: The flux of light per unit of emitting surface, expressed as lumens per square inch; very often expressed as candle-power per projected area in a given direction.

J

Joule: The work done by a current of one ampere flowing through a resistance of one ohm for one second. One watt acting for one second.

K

Kilowatt: 1000 Watts.

Kilowatt-Hour: The energy expended when one kilowatt of power is used for one hour.

L

Life: The period of time a lamp will operate before it "burns out."

Useful Life: The period of time an incandescent lamp will operate before the mean horizontal c. p. drops to 75% of its initial value.

Light: That form of radiant energy which produces visual sensation.

Luminous Intensity: The intensity with which light flux is emitted in a certain direction.

Luminosity: A term expressing the brightness of a surface from which light arises as a result of either diffusion or emission.

Lux: A unit of illumination, equal to one lumen per square meter.

M

"Mazda": The trade name for the incandescent lamp representing the highest development in the art of lamp making; at present a tungsten filament lamp.

Mean Horizontal Candle-Power: The average intensity of a light in all the directions lying in a horizontal plane.

Mean Lower Hemispherical Candle-Power: The average of the intensities of a given light source in all directions of the lower hemisphere. Equal to the total flux (lumens) in the lower hemisphere divided by 2.

Mean Spherical Candle-Power: The mean spherical candle-power of a lamp is the average of its intensities in all directions and is equal to the total flux (lumens) emitted by the lamp divided by 4.

Mean Upper Hemispherical Candle-Power: The average of the intensities of a given light source in all directions of the upper hemisphere. The total flux (lumens) emitted within the upper hemisphere divided by 2.

Microfarad: One millionth of a farad.

Most Economical Efficiency: The efficiency at which a lamp should be operated so as to give the least total cost, taking into consideration both renewals and cost of energy.

O

Ohm: The unit of electrical resistance. The resistance of a column of mercury one square millimeter in cross-sectional area and 106 centimeters in length.

Ohm's Law: The fundamental law of flow of electricity in a circuit. The rate of flow (amperes) is equal to the electric pressure (volts) divided by the resistance (ohms).

Opalescent: The property of certain kinds of glass which renders it a diffuser of light by reason of its containing small white particles which deflect the rays of light as they pass through.

P

Performance: The performance of lamps or a class of lamps is the information as to their operation under different conditions. This information is usually put in the form of curves showing the variation of voltage, current, resistance, power consumption, efficiency and life, with candle-power; all expressed in percentage of normal efficiency values.

Polarity: Direction of difference of potential. A distinction between the positive and negative terminals of a piece of electric apparatus.

Potential: Difference of electric pressure. Voltage.

Power: Rate of doing work. Units of power are the horse-power and the watt (or kilowatt). 1 horse-power = 746 watts.

R

Radiation: The propagation of energy in the form of ether waves. A small part of the radiation from an incandescent body is visible, that is, is capable of producing a sensation in the eye.

Reflector: A device for modifying the distribution of light giving sources. Often called a shade.

Regulation: The rise of voltage from full load to no load expressed as per cent of the full load voltage. Electrical supply apparatus is said to have good regulation when its voltage is comparatively constant under varying conditions of load.

Regulator: A device which automatically keeps the voltage nearly constant..

Resistance: The property of a material by reason of which opposition to the flow of electric current is offered. It is measured in ohms.

S

Series. A system of connection whereby the same current flows through each of several pieces of apparatus.

Shade: An opaque or translucent body used to keep the direct rays of a light from falling upon the eye.

Shunt: A by-path in a circuit.

Specific Consumption: The power consumption per unit of light output. Usually expressed in watts per horizontal candle-power.

Standard Lamp: A lamp of known intensity used in photometering other lamps.

Storage Battery: One or more electrolytic cells which during a process of charging accumulate energy which is recoverable at a later time when discharging.

T

Tip Candle-Power: The candle-power of an incandescent lamp measured in the direction of its tip.

Transformer: An induction device for changing the voltage of an alternating current supply.

Tungsten: A rare metal used in the production of the present "Mazda" lamp filaments.

U

Useful Life: The time an incandescent lamp should be operated for best economy of light production.

V

Visual Acuity: The ability of the eye to distinguish fine details.

Volt: A unit of electric pressure. A volt is that degree of electric pressure which will cause one ampere of current to flow through a resistance of one ohm.

Voltage: Pressure expressed in volts.

W

Watt: A unit of power. The rate of energy transformation when a current of one ampere flows at a pressure of one volt.

Watt-Hour: The energy consumed when one watt of power is maintained for one hour.

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